South Saskatchewan Regional Plan

Water Quantity and Quality Modelling Results

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EXECUTIVE SUMMARY

Alberta Environment (AENV) carried out a number of in-house computer model exercises in 2009 and early 2010 to support the South Saskatchewan Regional Plan (SSRP). The Environmental Modelling Team of Regional Environmental Management in the Southern Region conducted the modelling work. This report describes the water modelling work undertaken by AENV and summarizes the results generated by the models.

The models used by the team fall into two main categories of *Water Allocation* and *Water Quality*. Simulation runs were created for the SSRP scenarios of **Base Case, Stewardship** and **Development** respectively.

The Water Resources Management Model was used for water allocation modelling. The WRMM matches water supplies and demands in a river basin during a long-term time series. For the SSRP the water supplies during the historical period 1928-2001 are matched on a weekly basis with demands.

The impacts of different SSRP scenarios on water quality conditions of the Bow River were assessed by the Bow River Water Quality Model (BRWQM), which is an integrated system of selected surface water quality and quantity models. BRWQM modelling for the current SSRP study covers the Bow River reaches between the Bearspaw Dam and Bassano Dam. The next phase will cover the Bow River reach from Bassano Dam to the mouth.

Outputs from the Water Allocation model were fed into the integrated water quality model. The Bow River boundary flow outputs between the period of 1990 and 2001 from the WRMM model were processed and compiled, since this is the only overlapped simulation period between the WRMM and BRWQM models.

A special set of scenarios termed drought scenarios were generated for the Base Case, Stewardship and Development scenarios respectively. The purpose is to examine the performance of storage and determine the impacts to the categories of Irrigation, Non-Irrigation and Apportionment if extreme dry years were experienced one after another. The water supply data used by the model was modified so that nine of the driest years in the record set were repeated in a back-to-back sequence. These are considered to be hydrological droughts i.e., years with an annual natural flow of less than 6 million dam^3 (~ lower decile in 74 years of historical natural flow records) measured at the Saskatchewan border. The dry years that are repeated in sequence in the historical time series for this exercise are: 1931, 1936, 1941, 1944, 1949, 1977, 1984, 1988, and 2001. The 2001/2002 drought was analyzed only in the water quality model exercise, while all the other droughts were analyzed in both water allocation and water quality modelling.

Key findings from Water Allocation modelling

- There is not a large difference in performance in meeting Apportionment among scenarios. The Stewardship Scenario has the best Apportionment performance, while the Development scenario has the least performance of the scenarios.
- In all scenarios, Bow River junior licences have poor performance likely the result of being cut off by the Water Conservation Objectives or Instream Objectives on the river. Irrigation Districts throughout the basin show good performance in all scenarios with the best results in the Stewardship scenario.
- Instream results are basically the same across all scenarios, with slight improvement shown in the Stewardship scenario over the Base Case and Development scenarios.

The following messages were derived from our analysis of the drought events.

- Potential impact on apportionment – frequency of failures to meet apportionment increases from Stewardship to Development Scenario. More licences (even senior licences) would have to be cut off if apportionment has to be met in all drought events. Delivery to Saskatchewan was generally within the low delivery range (50 to 55% of annual natural flow) in all scenarios.
- Potential deficit to licences in the Bow Basin – deficit generally increases from the Stewardship to Development Scenario. However, significant deficits occur to junior non-irrigation and irrigation licences in all drought scenarios. There are minor deficits to senior licences and irrigation districts with large internal storage in the Bow basin.
- Potential deficit to licences in the Oldman Basin including southern tributaries – deficit generally increases from the Stewardship to Development Scenario. However, substantial to significant deficits occur to all junior and senior licences (irrigation and non-irrigation including irrigation districts) in all drought scenarios.
- Potential impact to major provincial storage including southern tributaries – While the major storage reservoirs can withstand one drought year, in nearly all of the back to back droughts the storage is exhausted by the end of the second drought year. This suggests that our major storage cannot support more that two consecutive drought years in a row. It was also observed that storage takes time to recover in the year after a drought.

  Oldman Reservoir storage was depleted to the operating minimum level during the latter half of the second year in most drought events. This means apportionment and/or downstream IO (instream objectives) could not be met.

In southern tributaries, the St. Mary Reservoir was frequently depleted to the operating minimum level in single low flow years even in the Stewardship Scenario (without drought). Back to back drought events would worsen the situation with relatively more impact in the Development than the Stewardship Scenario.

Key findings from Water Quality modelling

- The primary water quality risk in the Bow River is dissolved oxygen (DO), as it is directly related to fish health in the Bow River. Nutrients in the Bow River do not directly affect fish health, but they can depreciate the river water quality conditions through encouragement of excessive growth of aquatic vegetation, which can then introduce inferior DO conditions for fish survival. The model predictions reveal that acceptable DO conditions could generally be sustained in the Bow River under the Stewardship Case. However, much less acceptable DO conditions and an elevated exceedance probability of DO objectives are expected to occur under both the Base and Development Cases;

- Phosphorus was identified as one of the key nutrient parameters that triggered the over-growth of vegetation and low DO conditions in the Bow River. The primary phosphorus loading for the Bow River is from the City of Calgary's waste water treatment plants (WWTP). Proper management of the total loadings from these WWTPs, as given in the Stewardship Case, is the critical measure for controlling the water quality risks in the Bow River;

- Excess Total Suspended Solids (TSS) concentrations could also affect fish productivity. The predicted TSS exceedance frequencies are very consistent among the three SSRP scenarios, and are mainly related to the non-point source loadings into the Bow River;

- Higher water temperature could also potentially become a risk for fish health, although the model predictions indicate that the probability of the Bow River water temperature exceeding the BRBC WQO limits is very unlikely for the three SSRP scenarios.

- All the SSRP scenario simulation results are based on the conditions for the Bow River between Bearspaw Dam and Bassano. Caution needs to be applied when extrapolating the conclusions of these three SSRP scenarios from this study area to the other areas of the Southern Region.

The following key findings based on the analysis of the drought simulation results are:

- Dissolved oxygen and nutrient conditions are expected to become worse under the drought condition for the Bow River reach within the City of Calgary limit, because of the decreased amount of upstream water to assimilate the major

waste loadings from Calgary's WWTPs. However, DO and nutrient conditions would be much improved for the lower reach of the Bow River, due to decreased amounts of source loadings from this range of river under the drought condition, as well as the river's self-remedy functions such as re-aeration and bio-chemical oxidation;

- TSS conditions are expected to be improved under the drought condition due to the fact that most TSS loadings to the Bow River are associated with storm water inflows, which would become much less significant under dry conditions;
- The overall water quality risks associated with drought conditions are much lower for the Stewardship Scenario when compared with the Base and Development Scenarios due to lower amounts of water diversions at the upstream of the Bow River as well as the reduced wastewater returns from Calgary's WWTPs.

Key findings from Hydroclimate Modelling

In addition to the modelling completed for the base, stewardship and development scenarios, two contracts were awarded to study the impact of climate change and variability on hydrology, primarily on natural surface water supply. Under a *Federal and Provincial Joint Initiative on Climate Change Adaptation Study*, a contract was awarded through NRCAN (Natural Resources Canada) to Dr. Dave Sauchyn, University of Regina to study climate variability in SSRP. Another contract was awarded by AENV to Golder Associates to model the impacts of climate change and variability on the hydrology of SSRP.

The overall findings indicated that the impact of climate change on SSRP annual stream flow ranges from +5% to -30%. Climate variability would further decrease stream flows by 25% or more in dry years, and to a much lesser extent in wet years. This suggests that low annual flows are affected to a larger degree by changes in climate variability than are high annual flows, which has implications for water management in the moisture-limited environment of the low basin yield areas of the SSRP.

TABLE OF CONTENTS

LIST OF ACRONYMS

AENV	Alberta Environment
BRBC	Bow River Basin Council
BRID	Bow River Irrigation District
BRWQM	Bow River Water Quality Model
CA	Cellular Automata Model
CV	Coefficient of Variation
dam^3	Decametre. 1 cubic decametre = 1000 m^3 = 1 mega litre (million litres) = 0.8107 acre-ft
DO	Dissolved Oxygen
FRC	Fish Rule Curves
GCM	Global Circulation Model
HEC-RAS	Hydrologic Engineering Centre-River Analysis System
HSPF	Hydrological Simulation Program - Fortran
IDM	Irrigation District Model
IO	Instream Objectives
MODFLOW	Modular Finite-Difference Flow Model
QHM Model (QUALHYMO)	Quality Hydrologic Model
SAWSP	Special Areas Water Supply Project
SEV	Severity of Ill Effects
SSRB	South Saskatchewan River Basin
SSRP	South Saskatchewan Regional Plan
STRIBS	Southern Tributaries
SWAT	Soil Water Assessment Tool
TAU	TransAlta Utilities
TDP	Total Dissolved Phosphorus
TP	Total Phosphorus
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
WA	Water Allocation
WASP	Water Quality Analysis Simulation Program
WCO	Water Conservation Objective
WID	Western Irrigation District
WQ	Water Quality
WQO	Water Quality Objective
WRMM	Water Resources Management Model
WWTP	Waste Water Treatment Plant

INTRODUCTION

Alberta Environment (AENV) carried out a number of computer model exercises in-house in 2009 and early 2010 to support the South Saskatchewan Regional Plan (SSRP). The Environmental Modelling Team of Regional Environmental Management in the Southern Region conducted the modelling work. The models used by the team fall into two main categories of *Water Allocation* and *Water Quality*.

The Water Allocation model that AENV uses in the Southern Region is the Water Resources Management Model developed by the department. To undertake Water Quality modelling, four models developed by various agencies of the U.S. Government are employed in an integrated system. In a final step, outputs from the Water Allocation model were fed into the integrated Water Quality models to understand water quality impacts of differing scenarios used in the SSRP.

Simulation runs were created for the SSRP scenarios of **Base Case, Stewardship and Development** respectively. This report describes the modelling work undertaken by AENV for these scenarios and summarizes the results generated by the models. Background information on the models used and key messages as a result of the model work are included. In addition, other on-going modelling activities and future directions as related to the SSRP are described.

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MODEL BACKGROUND

Water Allocation Model

Water Resources Management Model - WRMM

Alberta Environment began development of the Water Resources Management Model (WRMM) in 1979 for application in the original South Saskatchewan River Basin (SSRB) Planning Program (1982-1985). It has subsequently been used in all substantive water management planning and operational studies in the South Saskatchewan and Milk River basins, including the development of the SSRB Water Management Plan (2005) and the current South Saskatchewan Regional Plan (SSRP).

The WRMM matches water supplies and demands in a river basin during a long-term time series. For the SSRP the water supplies during the historical period 1928-2001 are matched on a weekly basis with demands.

Principal inputs to the model are:

- Historical climatic and river natural flow data (1928 – 2001);
- Canadian share of St. Mary River natural flow;
- Irrigation district and private irrigation consumptive use and return;
- Non-irrigation withdrawals (municipal, industrial, other projects);
- Instream objectives (fish habitat and water quality) and Water Conservation Objectives;
- Reservoir and canal structure capacities and discharge limitations;
- Licence priorities, conditions and volume/rate limits;
- Operating policies for structures;
- 1969 Apportionment Master Agreement.

For each scenario, results are calculated for all demands, as well as structure storages and flows. The performance of the demand components is determined in terms of deficits (failure to meet the component requirement due to insufficient water). More information about the WRMM model setup for the SSRP is included in Appendix A.

South Saskatchewan Regional Plan (SSRP) Sub Basin Models

There are some technical limitations and practical considerations related to the simulation of an extremely complex river system such as in the SSRP. Therefore, the WRMM computer simulation for the SSRP consists of several smaller models. The inputs and outputs for the various WRMM models are utilized in a manner such that the

water balance results would be very similar to what would happen if there was a single model. These models include: TransAlta Utilities (TAU), South Saskatchewan River Basin (SSRB) main model, Southern Tributaries, Highwood Diversion Plan, Special Areas Water Supply Project (SAWSP), Acadia and Milk. The component models are briefly described as follows.

TAU model

In the Bow main stem, on-stream storage is licensed to TransAlta Utilities (TAU). A WRMM model of the upper Bow basin (above Bearspaw reservoir) is run to simulate TAU operations during the 1928-2001 period and to obtain a file of flow releases from Ghost reservoir. Water availability in the rest of the basin reflects current TAU operations.

Main SSRB model

Output from the TAU model serves as input into the main SSRB model of four sub river basins within the SSRP (Red Deer, Bow below Bearspaw, Oldman and South Saskatchewan sub basin) combined. Although much of the Red Deer basin is outside of the SSRP boundaries, it is included in the main SSRB model because of the role the Red Deer River and Glennifer reservoir play in managing apportionment commitments to Saskatchewan. The Red Deer, Bow, Oldman and South Saskatchewan sub basins are managed as a unit for meeting apportionment.

Stribs model

The Southern Tributaries to the Oldman River (Waterton, Belly and St Mary Rivers) are modelled separately from the SSRB main model. The outputs from the Southern Tributaries model provide input into the main SSRB model at a number of points to reflect return flows from the major irrigation projects and inflows from the southern tributary rivers to the Oldman.

Highwood Diversion Plan model

The Highwood, Little Bow and Mosquito Creek basins are modelled separately from the SSRB main model. These basins are the subject of the Highwood Diversion Plan, which was completed in 2006 and approved by the Natural Resources Conservation Board in 2008. This model reflects the approved diversion plan and is used as input to the SSRB main model at two points (Highwood River confluence and Travers reservoir).

SAWSP and Acadia model

There are two proposed major projects in the Red Deer River sub basin included in the SSRP Development Scenario that may be built within the planning horizon of the SSRP. These projects have their own separate WRMM simulations. The two projects are of sufficient size to potentially affect apportionment management, so the outputs of the individual models are used by the SSRB main model. The first of these is the Special Areas Water Supply Project (SAWSP) proposed to withdraw water from the Red Deer River near Nevis and to supply water to Sounding and Berry Creeks for irrigation and

wildfowl (such as Ducks Unlimited) projects. The demand flow requirements from the model are used to produce a single demand value representing the overall SAWSP demand. The single demand is used by the main SSRB model at the Nevis location point.

The second major project is an irrigation proposal in the Acadia Valley area. Similar to the Special Areas project, the output from the WRMM simulation for the Acadia Project is represented as a single demand at the Bindloss location point upstream of the Saskatchewan border in the SSRB main model.

Milk model

Finally, the Milk River basin is modelled as a separate WRMM simulation that has no direct linkage relationship with the other models. However, outputs from this model are reported in overall SSRP result summaries.

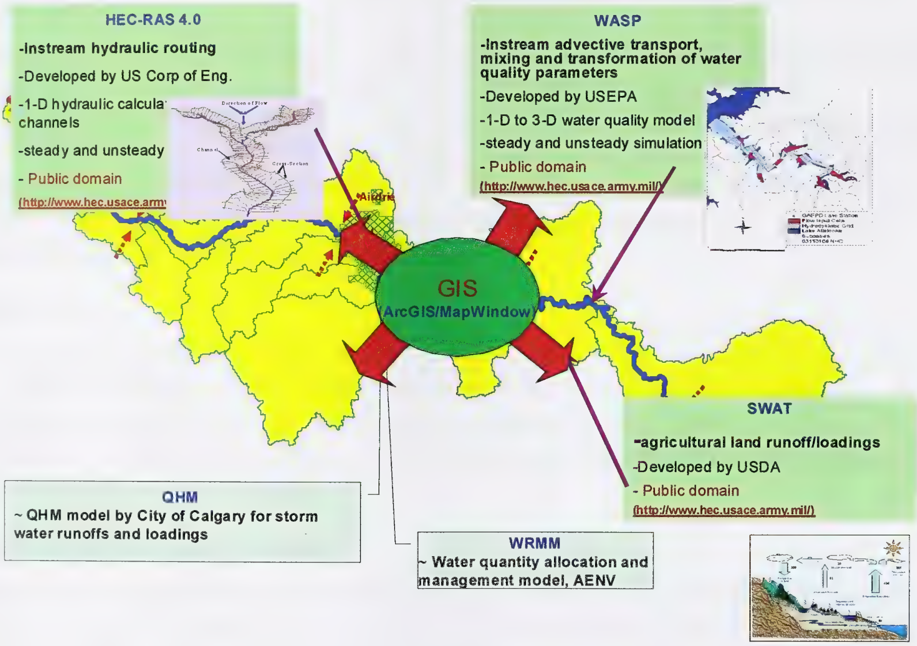
Bow River Water Quality Models

BRWQM System

(Bow River Water Quality Model)

The impacts of different SSRP scenarios on water quality conditions of the Bow River were assessed by the Bow River Water Quality Model (BRWQM), which is an integrated system of selected surface water quality and quantity models (see Figure WQ 1). The BRWQM is a very complex modelling system and as such is developed under different phases.

Figure WQ 1
Integrated Water Quality Modelling System for the Bow River

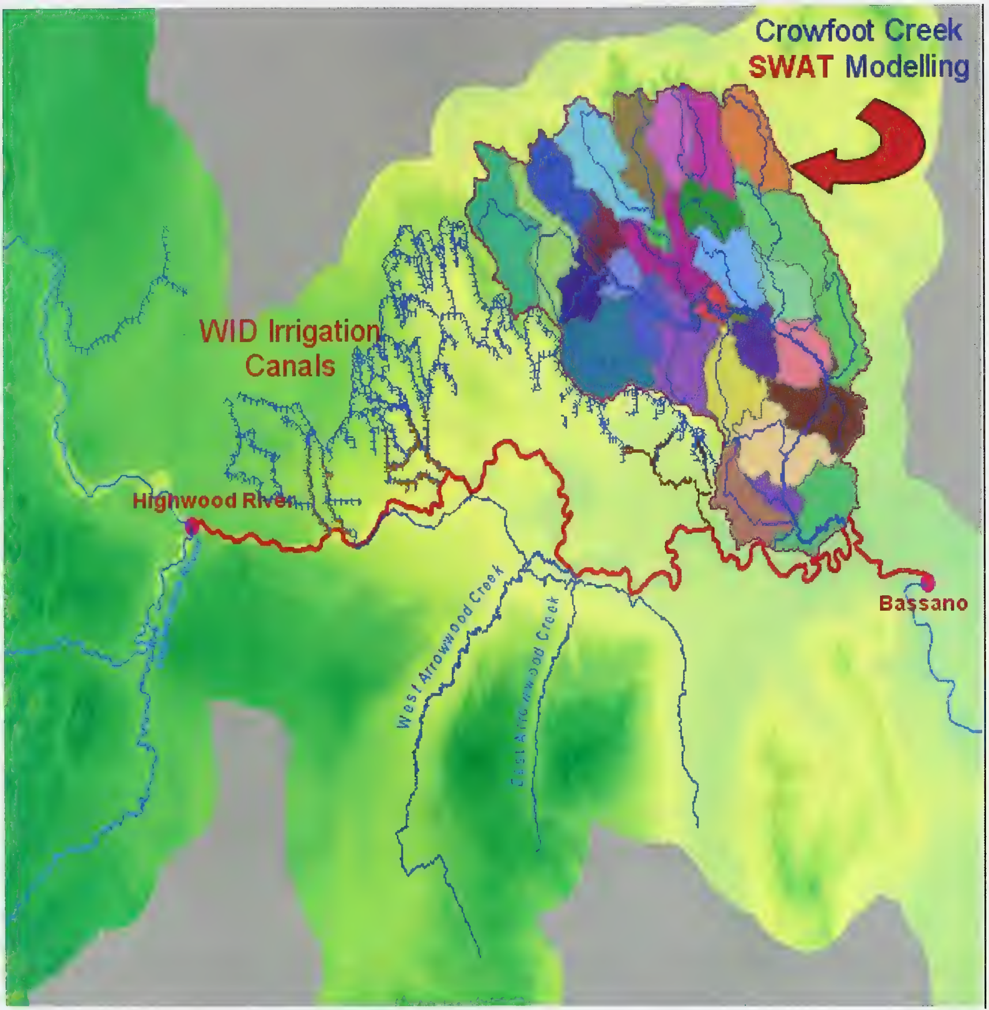


Phase I BRWQM development was initiated by the City of Calgary and Golder Associates in 2003 and focused on the Bow River reach mainly within the City of Calgary limits, i.e., from the Bearspaw Dam to its confluence with the Highwood River (Golder, 2004a, 2004b) (see Figure WQ 2). This reach of the Bow River is subjected to a number of major flow diversions by the City of Calgary and Western Irrigation District (WID). It also receives a number of substantial waste loadings from the City of Calgary's wastewater treatment plants (WWTPs), the storm water drainages, and some tributaries.

Figure WQ 2
BRWQM Model Development - Phase I

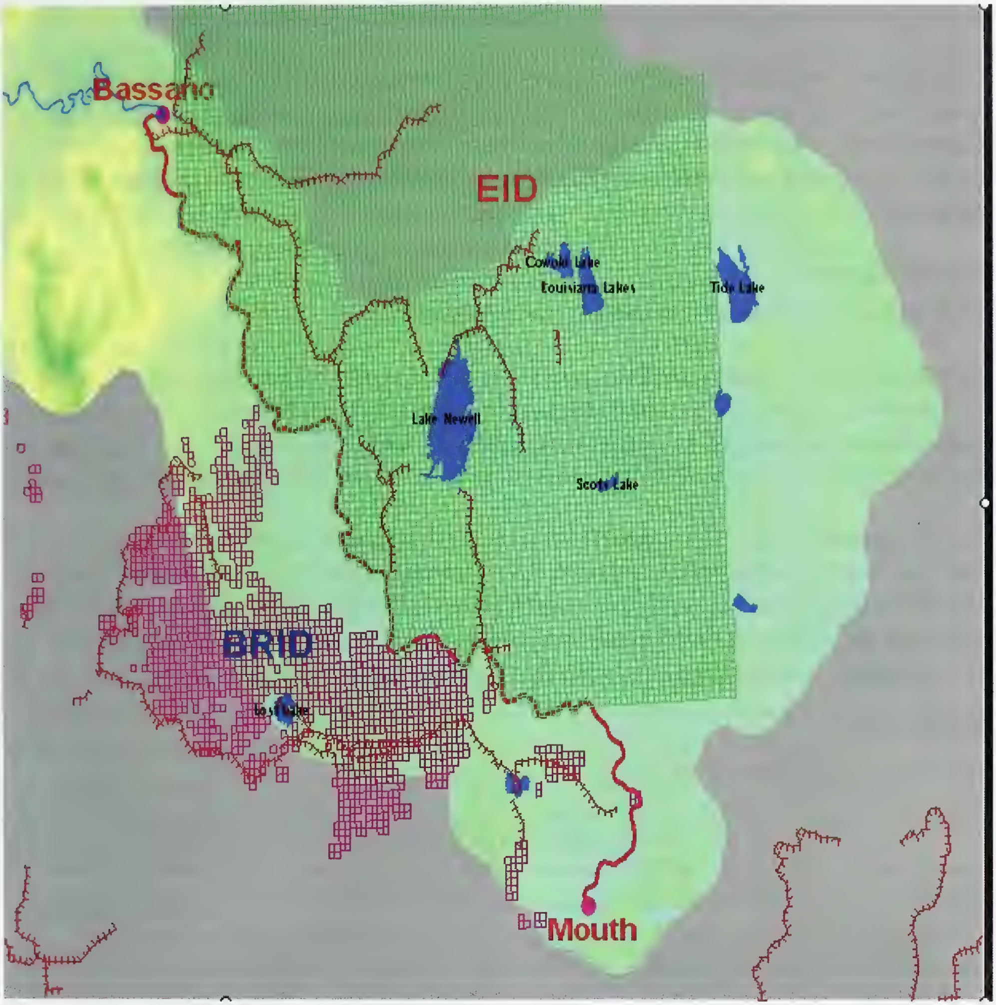
Under agreement with the City of Calgary, Alberta Environment (AENV) initiated Phase II BRWQM development in 2008 focusing on the Bow River reach downstream of the City of Calgary, i.e., from the Highwood River confluence to the Bassano Dam (see Figure WQ 3). The major loading sources within this Bow River reach include mainly the Western Irrigation District (WID) agricultural return flows and some natural drainage such as the Highwood River and the West and East Arrowwood Creeks. The Bow River Irrigation District (BRID) also diverts its irrigation flows at the downstream end of this reach of the Bow River.

Figure WQ 3
BRWQM Model Development - Phase II



The BRWQM modelling domain for the current SSRP study covers only the Bow River reaches between the Bearspaw Dam and Bassano Dam. Phase III BRWQM development is being undertaken to cover the Bow River reach from the Bassano Dam to the mouth (Figure WQ 4). The major loading sources within this reach include mainly the Bow River Irrigation District (BRID) and Eastern Irrigation District (EID) agricultural return flows.

Figure WQ 4
BRWQM Model Development - Phase III



The BRWQM system consists of a number of hydrological, hydraulic and water quality models that are highly recognized by modelling academics and have been widely applied in many river basins of North America and other parts of the world. The selected models for the BRWQM system and their individual roles are discussed below.

QHM Model – QUALHYMO

(Quality Hydrologic Model)QHM model is a continuous watershed model designed primarily for urban storm water applications. It was originally developed in 1983 by

Paul Wisner and Craig MacRae of the University of Ottawa. The QHM model is capable of simulating surface runoff, base flow, soil freeze and thaw, snowmelt and snow removal/disposal, retention pond and reservoir routing, evaporation and evapotranspiration, pollutant generation and routing and stream erosion potential.

In this study, the QHM model was applied to simulate storm water runoff and the associated pollutant loadings yielded from the Bow River catchments within the City of Calgary limits. The QHM provided the necessary storm water flow and loading time-series to support the related water quality model simulation for the main stem of the Bow River.

HEC-RAS Model

(Hydrologic Engineering Centre-River Analysis System)

HEC-RAS model is a highly credited one dimensional river analysis system that is capable of steady and unsteady flow simulation, movable boundary sediment transport/mobile bed computation, as well as water quality analysis. HEC-RAS is a public domain program that is currently supported and maintained by the U.S. Army Corps of Engineers.

In this study, the HEC-RAS model was applied to simulate time-varying inflows from multiple sources, water withdrawals and flow transport and routing along the length of the main stem of the Bow River between Bearspaw Dam and Bassano Dam. HEC-RAS provided the necessary flow volume and velocity time-series outputs to support the related water quality model simulation for the main stem of the Bow River.

SWAT Model

(Soil Water Assessment Tool)

The SWAT model is also a highly credited hydrological and water quality model developed by USDA (United States Department of Agriculture). The model is a public domain program with freely distributed source codes. The model is used to evaluate the effects of agriculture land use, climate changes, irrigation water demand and allocation, as well as agricultural best management practices. Its unique strength is to dynamically simulate the effects of agriculture management practice, land use and climate change on the yields of non-point source waste loadings from agriculture lands. The model is also capable of evaluating soil erosion control and the role of riparian ecosystems as related to agricultural best management practice. Recent research has reported that SWAT could be successfully coupled with the renowned groundwater model, MODFLOW (Kim N.W., et al., 2008). AENV is also exploring interfacing the SWAT model with the land use simulation tool, CA (Cellular Automata) model.

In the current study, SWAT was applied to assess the surface water runoff and the associated nutrient and sediment loading yields from the Crowfoot Creek watershed. Crowfoot Creek is a sub-catchment of the Bow River Watershed, and discharges the major portion of the agricultural return flows from WID into the Bow River. The SWAT

model was also used to simulate sediment erosion and transport during storm events in the Crowfoot Creek sub-watershed. SWAT provided the necessary flow volume and associated nutrient/sediment loading time-series to support the related water quality model simulation for the main stem of the Bow River.

WASP Model

(Water Quality Analysis Simulation Program)

WASP is one of the most widely applied water quality programs developed and maintained by the U.S. EPA. WASP helps users to interpret and predict water quality responses to natural phenomena or manmade pollutants. WASP is a dynamic compartment-modelling program for aquatic systems, including both the water column and the underlying benthos. WASP allows the user to investigate one, two and three dimensional systems, and a variety of pollutant types. The time varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are all represented in the model. The WASP model can be easily coupled with other surface water quantity models or groundwater models to support cumulative effects management practice.

In this study, the WASP model was applied to assess the fates of various pollutants after being discharged into the Bow River. The original WASP model source codes were modified by Golder Associates (Golder 2004a, 2004b) to account for the growth of aquatic vegetation (macrophyte and benthic algae), as well as their profound impacts on dissolved oxygen and nutrient dynamics in the Bow River. The WASP model was coupled with QHM, SWAT, and HEC-RAS models in this study to evaluate the cumulative in-stream water quality effects due to various loading discharges and water management practices along the main stem of the Bow River. WASP provided the dynamic time series of predicted water quality conditions for the Bow River to support the assessment of impacts from different SSRP scenarios.

Model Integration

The BRWQM is an integrated surface water modelling system that was developed through a number of steps. Firstly, each of the four models, QHM, SWAT, HEC-RAS or WASP, was calibrated and validated to determine a suitable set of constants and kinetic rates that allow the models to appropriately represent the flows and water quality conditions of the Bow River Basin within the modelling domain. The selected four models were then coupled together to form an integrated surface water modelling system to support the SSRP scenario simulations (see Figure 1).

In the integrated BRWQM system, the simulations of the selected models were carried out sequentially. The QHM and SWAT models needed to be configured and simulated at the front to provide the following pre-requisite outputs for the other models:
QHM ~ Storm water runoff flow rates and pollutant loadings yielded from the Bow River catchments within the City of Calgary limit;

SWAT ~ Storm water runoff and agricultural return flows, as well as the associated pollutant loadings yielded from the Bow River sub-catchment, Crowfoot Creek that is downstream of the City of Calgary.

Secondly, the HEC-RAS model was configured to account for the hydraulic routing and transport of the Bow River headwater inflow, the storm water inflows from the various Bow River sub-basins, and the numerous Bow River return flows from its urban sewage treatment plants and rural agricultural developments. The model was also configured to account for several diversion flows from the Bow River. The HEC-RAS model was simulated to provide the following pre-requisite outputs for the other model:

HEC-RAS ~ Time varying instream flow rates and segment water volumes for the main-stem of the Bow River from the Bearspaw Dam to the Bassano Dam.

Finally, all the outputs from the above three models were integrated to generate the complete set of boundary inputs required by the WASP model. The WASP model is considered as the core component of the BRWQM system, since it is used to simulate the cumulative fates of all the boundary point and non-point source waters after they enter the main-stem of the Bow River. For this reason, the WASP model was simulated at the final step to predict:

- WASP ~ fates of various water quality parameters (such as DO, nutrients, total suspended solids) along the mainstem of the Bow River.

In addition, the ArcGIS® program (Environmental Systems Research Institute-ESRI) was adopted in the BRWQM system to facilitate the model input preparation and compilation, model output processing and visualization, as well as results analysis.

Water Allocation and Water Quality Model Coupling

During SSRP scenario modelling, the BRWQM system was interfaced with the WRMM model. The Bow River basin is a highly managed flow system with a number of hydraulic dams and diversion canals to regulate Bow River flows in order to meet the water supply and demand needs from multiple license users. The WRMM model is applied to identify optimized flow operational plans for the Bow River and other major rivers under different dry and wet conditions.

During the SSRP scenario simulations, the WRMM model was applied first to simulate the Bow headwater flows at the Bearspaw Dam, the water withdrawals and the treated wastewater returns from the City of Calgary, as well as flow diversions and returns from other developments for different SSRP scenarios. The Bow River boundary flow outputs in the period between 1990 and 2001 from the WRMM model were processed and compiled, since this is the only overlapped simulation period between the WRMM and BRWQM models. The BRWQM system was configured using the formatted WRMM outputs to simulate only the period between 1990 and 2001 for all the SSRP scenarios.

MODEL ANALYSIS, RESULTS AND FINDINGS

Water Allocation

The Water Resources Management Model configuration used in the South Saskatchewan River Basin (SSRB) planning exercise was used in the South Saskatchewan Regional Plan (SSRP) scenario simulations. A general description of the SSRB model configuration is described in Appendix A. The SSRP simulations are labeled **Base Case, Stewardship** and **Development** respectively.

Common aspects among scenarios

There is no reliable forecast of what the climate and water supply might be during the future time horizon of the SSRP. It is assumed that the water supply and climate experienced in the past 74 years adequately captures the nature of wet and dry cycles that can be expected to occur, although the sequences will not be repeated exactly. The model uses the historical average weekly natural flows from 1928 to 2001 as its water supply. The same water supply data set is used in all of the scenarios.

The WRMM model keeps demands constant (i.e., does not grow demands) over time. In the case of SSRP scenarios, demands anticipated at the end of the planning horizon (2060) are used. For non irrigation, one set of demands is used across all years of a scenario. Differences between scenarios can be found in the differences to assumed demands. Similarly, one set of irrigation areas is used across all years of a scenario. The Base Case and Stewardship scenarios use the same irrigation areas, while the Development scenario uses a different area.

Irrigation demands, losses and return flows are variable in each year of the time record and different variable irrigation demand sets are used in each scenario respectively. The variable demands generated by Alberta Agriculture and Rural Development in the Irrigation District Model (IDM) for 1928 to 2001 are used as the basis of irrigation demands and returns in the WRMM model. For irrigation districts, variable losses and return flows created in the IDM are also used in the WRMM model. First Nations use and private irrigation are assumed to produce neither losses nor return flow.

With the exception of the City of Calgary, municipal return flows are assumed to occur near the raw water diversion point and are therefore not modelled. Instead, only net consumptive use (licensed consumption plus losses) are modelled as municipal demands. In addition to consumptive uses, the return flows for the two City of Calgary water plants are modelled as a constant proportion of diversion.

Instream Objectives (IO) and Water Conservation Objectives (WCO) are included in the model as targets for some licence categories and are the same in all scenarios. The model does not use Instream Flow Needs (IFN) as a target in any of the scenarios for any

licences. However, flow results are compared to IFN as a benchmark for information. See Appendix A for more information on IO, WCO and IFN.

A portion of the Oldman reservoir is reserved in the model for meeting Apportionment. To be conservative, the reserved zone for all years is based on the driest hydrological year. This zone is kept constant across all years of a scenario run, but the reserved zone is custom adjusted for each scenario. In this way, the model will meet apportionment commitments in all years in each scenario. In the case of hydrological drought scenario runs described later in this section, the reserved zone is not custom adjusted for the droughts.

Scenario Parameters

Municipal and other Non Irrigation Uses

Base Case

Comprehensive records of current water use for all licences are not available; however, it is believed that current demand is lower than licensed allocation. With closure of the Oldman and Bow basins, new allocations will not be issued. It is expected that licence transfers will be used to move unused allocation to other users so that by the year 2060, the current licensed allocation in the basins will be fully utilized.

Other features of the Base Case scenario:

- City of Calgary – A large proportion of the City's licence is unused today; however, by 2060 it is assumed that 98% of the City's existing allocation will be diverted. Returns are modelled at 83% of diversion (i.e., the modelled net use for Calgary is 17% of withdrawal).

- Other municipal/non-irrigation uses including First Nations – By 2060, 84% of existing allocation is assumed to be diverted. Net consumptive use is set to 73% of diversion.

- Red Deer basin (outside of SSRP) – By 2060, demands will reach current licensed allocation.

Stewardship Scenario

The Stewardship scenario assumes that present day water demand will be the same in 2060.

- City of Calgary – The City's current diversion and returns (2004 data) are used. Withdrawal is about 44% of the Base Case

- Other municipal/non irrigation uses – Demands are set at approximately 70% of Base Case demand.

- Red Deer basin – same as Base Case.

Development Scenario

With regard to non-irrigation, the Development scenario assumes the same demands as in the Base Case with the exception of the Red Deer basin which assumes that the allocation limit established in the SSRB Plan will be reached.

Irrigation

Base Case

Current irrigation areas are used in the models.

Irrigation Districts:

- 2006 irrigation acreages
- Losses ~ 3% of withdrawal
- Return flow ~ 22% of withdrawal

Private Irrigation:

- 2006 irrigation acreages
- First Nations – Current irrigated acreages.
- Red Deer basin – Current irrigation acreages.

Stewardship Scenario

The Stewardship Scenario uses the same areas as the Base Case, but losses and return flows from the large irrigation districts are reduced by half.

Irrigation Districts:

- Irrigated areas – Same as Base case
- Losses ~ 1.5% of withdrawal (half of the Base Case)
- Return flow ~ 11 % of withdrawal (half of the Base Case)

Private Irrigation:

- Same as Base Case.

Development Scenario

Irrigation areas are increased from the Base Case scenario with losses and return flows in irrigation districts kept the same as in the Stewardship scenario. Future large proposed projects and total build out of the Sheerness/Deadfish system is assumed in the Red Deer basin. These are described in the section: *"Water Allocation Modelling"*.

Irrigation Districts:

- Irrigated areas 110% of Base case
- Losses ~ 1.5% of withdrawal (half of the Base Case, same as Stewardship scenario)
- Return flow ~ 11 % of withdrawal (half of the Base Case, same as Stewardship scenario)
- WID planned increased storage included in this scenario

Private Irrigation:

- Irrigated areas 110% of Base case
- First Nations –Base Case with future commitments for Siksika expansion, Pikanii and Blood projects.
- Red Deer basin – Future proposed projects include Special Areas Water Supply (SAWSP), M.D. of Acadia, Sheerness/Deadfish projects. These increased demands in the Red Deer basin have potential to affect Oldman dam operation to meet apportionment.

Hydrological Drought Scenarios

A special set of scenarios termed drought scenarios were generated for the Base Case, Stewardship and Development scenarios respectively. The purpose is to examine the performance of storage and determine the impacts to the categories of Irrigation, Non-Irrigation and Apportionment if extreme dry years were experienced one after another. The water supply data used by the model was modified so that nine of the driest years in the record set were repeated in a back-to-back sequence. For example, 2001 was a very dry year but in 2002 the water supply rebounded and returned to a more normal state. This exercise asks the question: "What if 2001 happened again in 2002 instead of the more normal situation that actually occurred?"

Droughts of only two consecutive years in a row are modelled. The dry years that are repeated in sequence in the historical time series for this exercise are: 1931, 1936, 1941, 1944, 1949, 1977, 1984, 1988, and 2001. These are considered to be hydrological droughts i.e., years with an annual natural flow of less than 6 million dam^3 (~ lower

decile in 74 years of historical natural flow records) measured at the Saskatchewan border. Each of these low flow years was repeated in the following year to simulate a back to back drought event. That is, the years 1932, 1937, 1942, 1944, 1950, 1978, 1985, and 1989 are replaced with the previous year's data to create the drought. An additional year was added to the data series (2002 was used for the repetition of 2001). The impact of a repeated 2001 drought is examined but cannot be compared to the normal year of 2002 because the natural flow record set ends at 2001.

Results and Findings

Table WA1 shows the performance of various categories averaged over the 74 years of record. Results are provided for the categories of Apportionment (at the Saskatchewan border), Non Irrigation, Irrigation and Instream. Different categories have different performance measures.

Apportionment[1]

The model always attempts to meet apportionment. Of interest is how well the commitment is met over the 74 years of record in the model. The key measures selected for comparison among scenarios are:

- Average annual delivery to Saskatchewan expressed as a percent of natural flow.
- Frequency of low flow deliveries (i.e., less than 55% to 50% of natural flow) expressed as number of years out of 74 (also shown in the table as percent of 74 years).
- Number of years when delivery is less than half of natural flow.

Figure WA 1 compares the performance of the different scenarios in meeting Apportionment. There is not a large difference in performance in meeting Apportionment among scenarios. The Stewardship Scenario has the best Apportionment performance, while the Development scenario has the least performance of the scenarios.

Non Irrigation

Two performance indicators are listed for different licence groups in the results table:

- Average Annual Deficit – Performance is determined by the annual deficit to the licence expressed as a percent of the allocation. For this exercise, the annual deficit is averaged over the 74 years of record.

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[1] **Apportionment Agreement:** An inter-provincial or international contract specifying the sharing of water resources from trans-boundary sources. For example, Alberta and Saskatchewan share the resources of the North and South Saskatchewan Rivers through apportionment agreements.

- Number of Years Deficit is over 10% – An average deficit of over 10% to a licence in a year is considered as large. The number of years (out of 74) the average deficit of a licence group exceeds 10% is counted.

In all scenarios, Bow River junior licences have poor performance, likely the result of being cut off by the WCO or IO on the river.

Irrigation

Deficits to irrigation are expressed differently than deficits to non-irrigation:

- Average Annual Deficit – Deficit to the crop demand over the course of a year is the performance measure commonly used in irrigation districts. Demand is expressed as the depth of water required per unit area specified in millimeters or inches to grow a crop. If the crop demand is not met, a deficit occurs. For example, if a crop requires 400 mm of water in a year, but only receives 250 mm, the deficit is (400 – 250 =) 150 mm. The data provided for crop demand in different areas is a net value that includes accounting for natural precipitation.

  Sometimes, crop demands exceed the water that can be supplied by a licence allocation for private irrigation. Therefore, deficits for private irrigation are modified to indicate if the full licence allocation was met instead of the full crop demand. Similar to the performance indicator for an irrigation district, the deficit to private irrigation licences is measured in millimetres.

- Number of years a deficit is over 100 mm – Deficits over 100 mm are considered to be significant deficits to a crop. The farming community has indicated that if this occurs in succession and/or frequently, severe economic hardship can result. The number of years (out of 74) the average deficit of a licence group exceeds 100 mm is counted.

Similar to non-irrigation, the Bow junior irrigation licences have the greatest deficits in all scenarios. Irrigation Districts throughout the basin show good performance in all scenarios with the best results in the Stewardship scenario.

Instream

Instream objectives (IO), Instream flow needs (IFN) and Water Conservation Objectives (WCO) have been identified in the South Saskatchewan River Basin Plan for the major reaches of the Bow and Oldman rivers. The model uses IO or WCO as flow targets under certain circumstances. The model does not try to satisfy IFN.

The flow targets are specified for each week over the 74 year period of record. The number of weeks that model results fall below a flow target in a specific reach is counted and expressed as a percent of the total number of weeks in the record (74 x 52 = 3,848 weeks). For example, in the Base Case scenario, the flow results for the Bow

River below Bassano dam were below WCO for 1,308 weeks = 34% of the all the weeks in the 74 year period of record.

Figures WA2 and WA3 show how often and by how much (frequency and magnitude) the model flows are above or below WCO over the course of a year for specific reaches in the Bow and the Oldman rivers. The x-axis shows week numbers starting on January 1 (week 1) and ending at December 31 (week 52) of the year. Spikes above the zero line illustrate when modelled flows are above WCO. Spikes below the zero line illustrate when modelled flows are below WCO. The charts show that generally on the Bow upstream of Bassano, flows are almost always above WCO in winter. This is because of TransAlta operating procedures. Irrigation operations in the summer and autumn will frequently drop river flows below WCO in the lower reaches.

Instream results are basically the same across all scenarios, with slight improvement shown in the Stewardship scenario over the Base Case and Development scenarios.

Water Allocation Drought Modelling Key Findings

Table WA2 compares delivery to Apportionment (expressed as % of natural flow) as well as detailed deficits to Non-Irrigation (expressed as % of licence) and deficits to Irrigation (expressed in mm) in the second year of back to back droughts. The first year of a back-to-back drought is the same in standard scenario runs and drought scenario runs. Years marked with a 'D' in the table are the second year of the drought. Detailed deficits in the year *after* a back-to-back drought are included in the table to determine if the drought has an "echo" effect on subsequent years as storage starts to recover. Note that 2002 and 2003 cannot be compared to standard scenario runs because the time series data is not available for those years. Figures WA4 and 5 show comparisons of storage elevations between the Stewardship scenario and the Stewardship Drought scenario for the Oldman and St. Mary reservoirs. Note that the model assumes reservoirs are in place for all of the years of the simulation. In other words, the model uses yesterday's hydrology with today's demands and infrastructure. The tables and plots demonstrate that in the majority of situations, a back-to-back drought appears to linger into the next year with impacts to apportionment, storage and deficits.

The following messages were derived from our analysis of the second year of these drought events.

1) Potential impact on apportionment – frequency of failures to meet apportionment increases from Stewardship to Development Scenario. More licences (even senior licences) would have to be cut off if apportionment has to be met in all drought events. Delivery to Saskatchewan was generally within the low delivery range (50 to 55% of annual natural flow) in all scenarios.

2) Potential deficit to licences in the Bow Basin – deficit generally increases from the Stewardship to Development Scenario. However, significant deficits occur to

junior non-irrigation and irrigation licences in all drought scenarios. There are minor deficits to senior licences and irrigation districts with large internal storage in the Bow basin.

3) Potential deficit to licences in the Oldman Basin including STRIBs – deficit generally increases from the Stewardship to Development Scenario. However, substantial to significant deficits occur to all junior and senior licences (irrigation and non-irrigation including irrigation districts) in all drought scenarios.

4) Potential impact to major provincial storage including STRIBs – The plots show that while the major storage reservoirs can withstand one drought year, in nearly all of the back to back droughts the storage is exhausted by the end of the second drought year. This suggests that our major storage cannot support more than two consecutive drought years. The plots also illustrate that the storage takes time to recover in the year *after* a drought.

   Oldman Reservoir storage was depleted to the operating minimum level during the latter half of the second year in most drought events. This means apportionment and/or downstream IO (instream objectives) could not be met. In STRIBs, the St. Mary Reservoir was frequently depleted to the operating minimum level in single low flow years even in the Stewardship Scenario (without drought). Back to back drought events would worsen the situation with relatively more impact in the Development than the Stewardship Scenario.

Figure WA 1 – Comparing Apportionment Performance

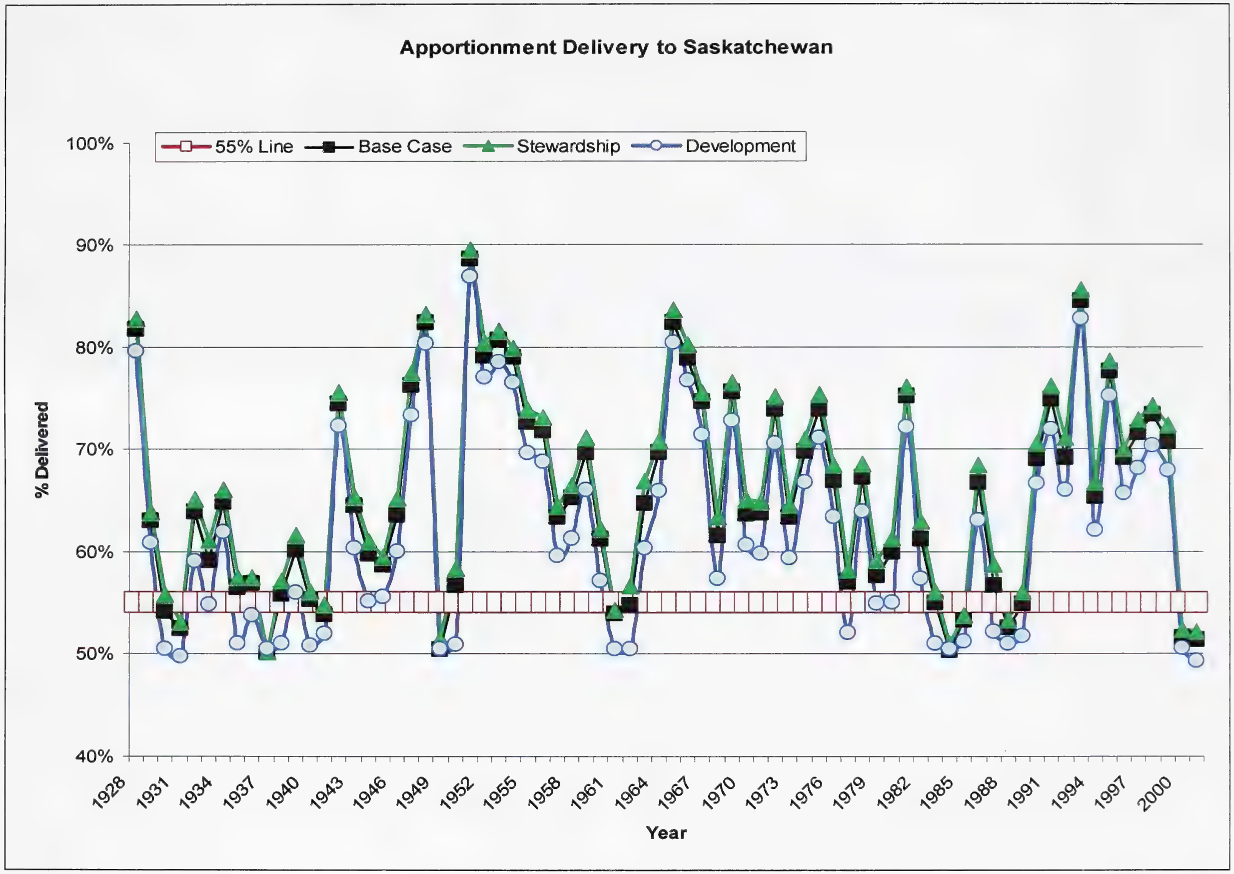


Table WA 1 – WRMM Results Summary

Apportionment	Base Case 1928 to 2001	Base Case Drought	Stewardship 2 1928 to 2001	Stewardship 2 Drought	Development 1928 to 2001	Development Drought
Average Annual Delivery to Saskatchewan (% of Natural Flow)	65%	64%	66%	65%	62%	60%
Frequency of Low Delivery (Less than 55% of Natural Flow)	16/74 = 22% of years	23/75 = 31% of years	11/74 = 15% of years	19/75 = 25% of years	27/74 = 36% of years	33/75 = 44% of years
Years where delivery is less than 49% of Natural Flow	0	3	0	2	0	5

Non Irrigation	Base Case 1928 to 2001: Average Annual Deficit	Base Case 1928 to 2001: Number of years deficit over 10%	Base Case Drought: Average Annual Deficit	Base Case Drought: Number of years deficit over 10%	Stewardship 2 1928 to 2001: Average Annual Deficit	Stewardship 2 1928 to 2001: Number of years deficit over 10%	Stewardship 2 Drought: Average Annual Deficit	Stewardship 2 Drought: Number of years deficit over 10%	Development 1928 to 2001: Average Annual Deficit	Development 1928 to 2001: Number of years deficit over 10%	Development Drought: Average Annual Deficit	Development Drought: Number of years deficit over 10%
Bow Juniors	51%	74/74	54%	75/75	43%	74/74	46%	75/75	54%	74/74	57%	75/75
Oldman Juniors	5%	11/74	12%	23/75	5%	12/74	12%	22/75	33%	61/74	40%	64/75
Southern Tribs Juniors	5%	12/74	10%	0	4%	10/74	10%	21/75	7%	15/74	11%	22/75
Milk Seniors	4%	7/74	4%	8/75	Same as Base Case		Same as Base Case Drought		Same as Base Case		Same as Base Case Drought	

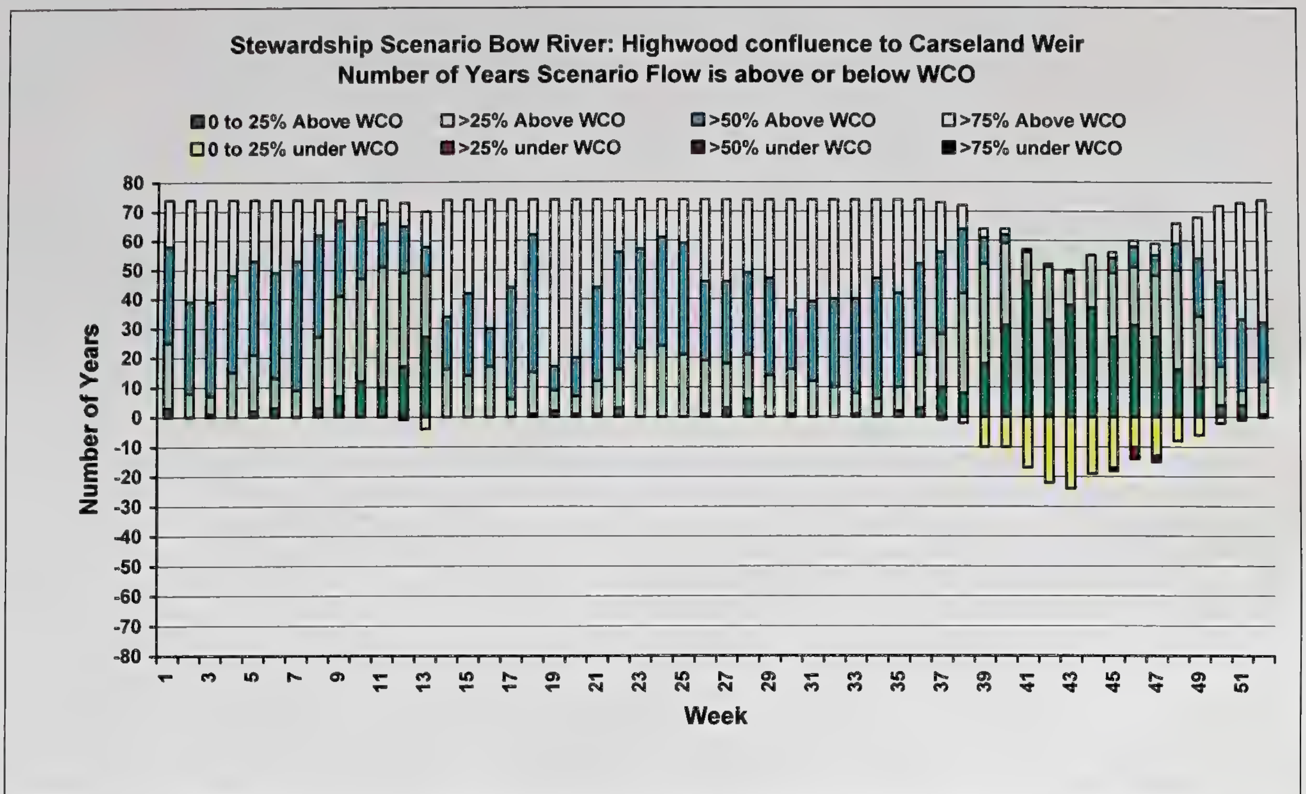
Irrigation	Base Case 1928 to 2001: Avg Annual Deficit (mm)	Base Case 1928 to 2001: Number of years deficit over 100 mm	Base Case Drought: Avg Annual Deficit (mm)	Base Case Drought: Number of years deficit over 100 mm	Stewardship 2 1928 to 2001: Avg Annual Deficit (mm)	Stewardship 2 1928 to 2001: Number of years deficit over 100 mm	Stewardship 2 Drought: Avg Annual Deficit (mm)	Stewardship 2 Drought: Number of years deficit over 100 mm	Development 1928 to 2001: Avg Annual Deficit (mm)	Development 1928 to 2001: Number of years deficit over 100 mm	Development Drought: Avg Annual Deficit (mm)	Development Drought: Number of years deficit over 100 mm
Bow Districts*	3	0	4	0	2	0	3	0	2	0	4	0
Bow Juniors**	38	10/74	52	16/75	32	8/74	47	14/75	58	17/74	75	23/75
Bow Seniors**	0	0	0	0	0	0	0	0	0	0	0	0
Oldman Districts*	2	0	10	4/75	1	0	9	3/75	16	4/74	30	10/75
Oldman Juniors**	9	2/74	26	6/75	9	2/74	27	7/75	94	26/74	121	33/75
Southern Tribs Districts*	13	1/74	24	7/75	7	1/74	18	6/75	10	1/74	23	7/75
Southern Tribs Juniors	10	1/74	20	6/75	9	1/74	19	6/75	11	1/74	23	7/75
Southern Tribs Seniors	36	5/74	42	8/75	36	5/74	42	8/75	36	5/74	42	8/75
Milk Juniors	185	59/74	205	62/75	Same as Base Case		Same as Base Case Drought		Same as Base Case		Same as Base Case Drought	

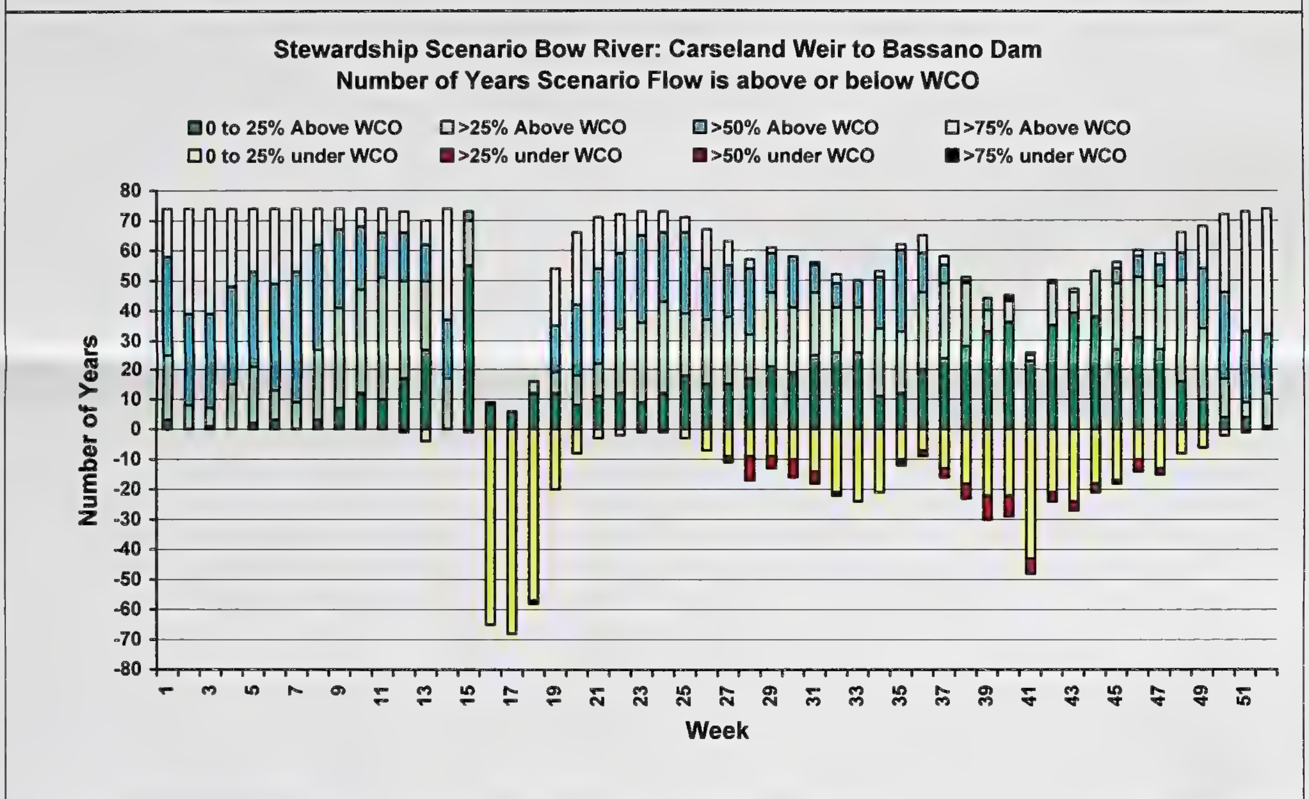
* Deficit based on crop demand
**Deficit to licence

Instream
Percent of Weeks where scenario flow is below target

Reach	Base Case 1928 to 2001: Below IO	Below WCO	Below IFN	Base Case Drought: Below IO	Below WCO	Below IFN	Stewardship 2 1928 to 2001: Below IO	Below WCO	Below IFN	Stewardship 2 Drought: Below IO	Below WCO	Below IFN	Development 1928 to 2001: Below IO	Below WCO	Below IFN	Development Drought: Below IO	Below WCO	Below IFN
BW00: Bassano Dam to the mouth	2%	34%	50%	2%	37%	52%	1%	29%	48%	2%	33%	50%	2%	36%	51%	2%	39%	52%
BW01: Carseland Weir to Bassano Dam	6%	20%	44%	9%	24%	46%	5%	18%	43%	8%	21%	44%	7%	22%	45%	10%	25%	47%
BW02: Highwood confluence to Carseland Weir	2%	5%	33%	4%	8%	34%	2%	5%	32%	4%	8%	33%	2%	5%	33%	4%	8%	35%
BW03: Elbow confluence to Highwood confluence	2%	4%	33%	4%	7%	34%	2%	4%	32%	3%	7%	33%	2%	4%	33%	4%	7%	34%
BW04: Bearspaw Dam to Elbow confluence	9%	13%		10%	16%		4%	8%		6%	10%	0%	9%	13%		10%	15%	
OM01: Below St. Mary confluence	0%	37%	81%	4%	41%	82%	0%	35%	79%	4%	40%	80%	1%	38%	80%	3%	41%	81%
OM02: Belly River confluence to St Mary confluence	0%	20%	62%	3%	25%	64%	0%	19%	60%	2%	23%	62%	0%	21%	61%	2%	25%	63%
OM03: Rocky coulee to Belly River confluence	1%	36%	55%	5%	39%	57%	1%	33%	52%	5%	37%	54%	1%	36%	56%	5%	40%	58%
OM04: LNID weir to Rocky Coulee confluence	4%	54%	49%	8%	57%	52%	4%	52%	46%	8%	55%	49%	4%	54%	49%	8%	57%	52%
OM05: Below Pincher Creek confluence to LNID weir	0%	37%	36%	3%	39%	40%	0%	36%	35%	3%	39%	39%	1%	33%	34%	3%	36%	38%
OM06: Below Oldman Dam to Pincher Creek confluence	1%	37%	30%	4%	39%	34%	1%	37%	30%	4%	40%	34%	0%	31%	27%	3%	35%	31%

Figure WA 2 – Bow WCO in Specific Reaches





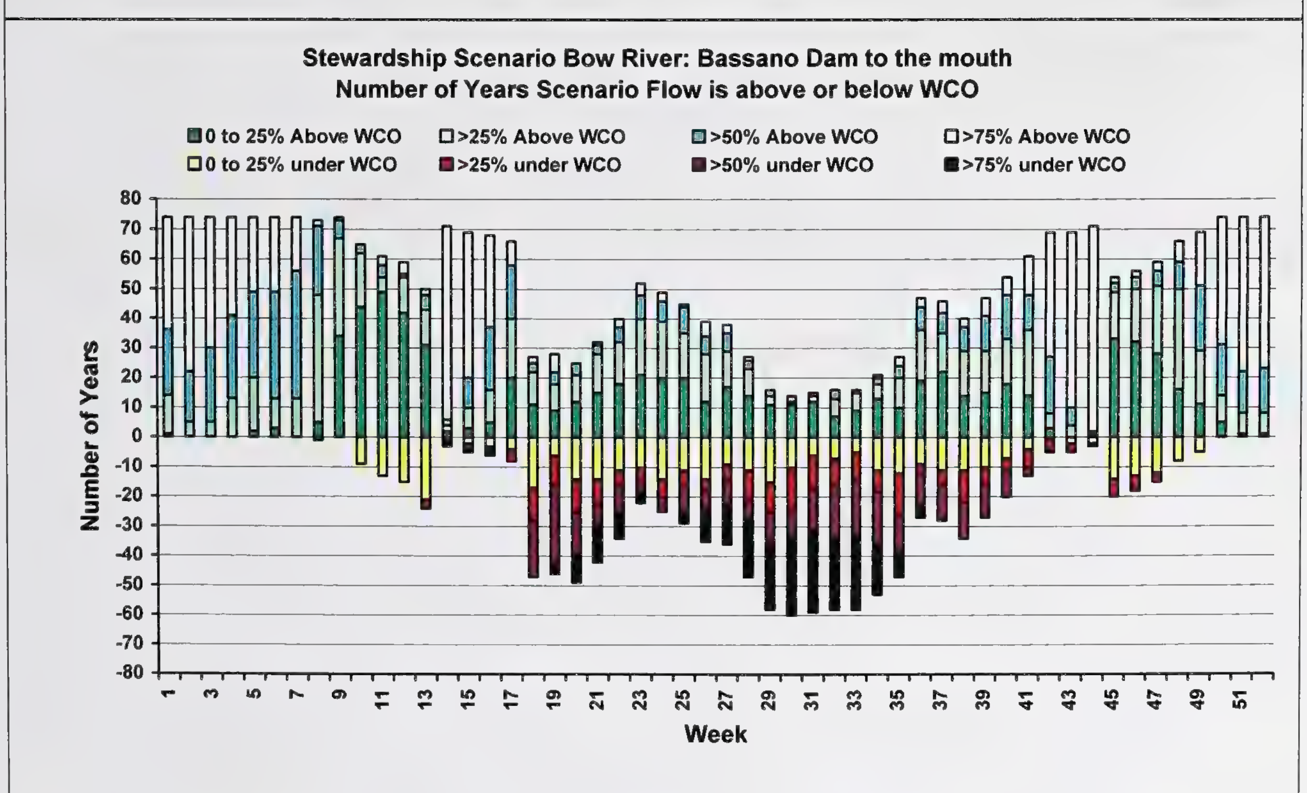
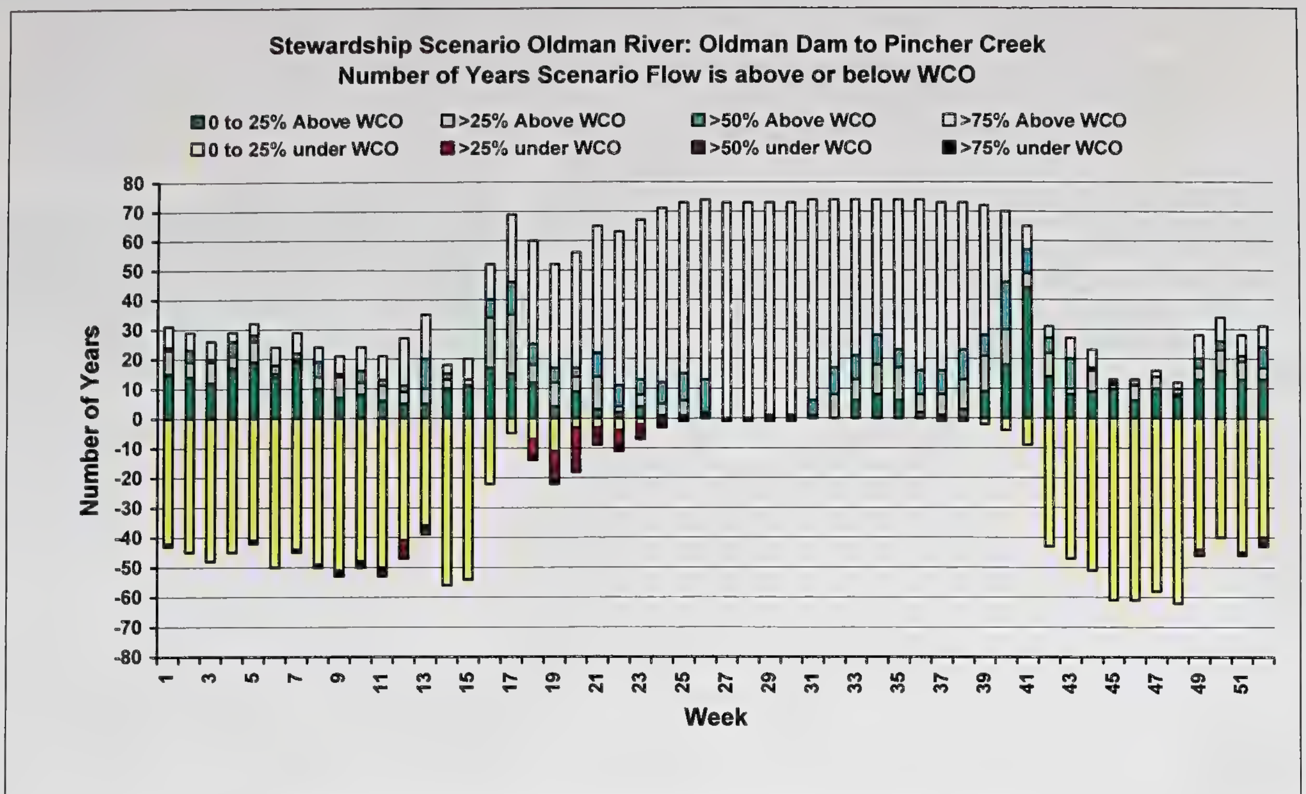
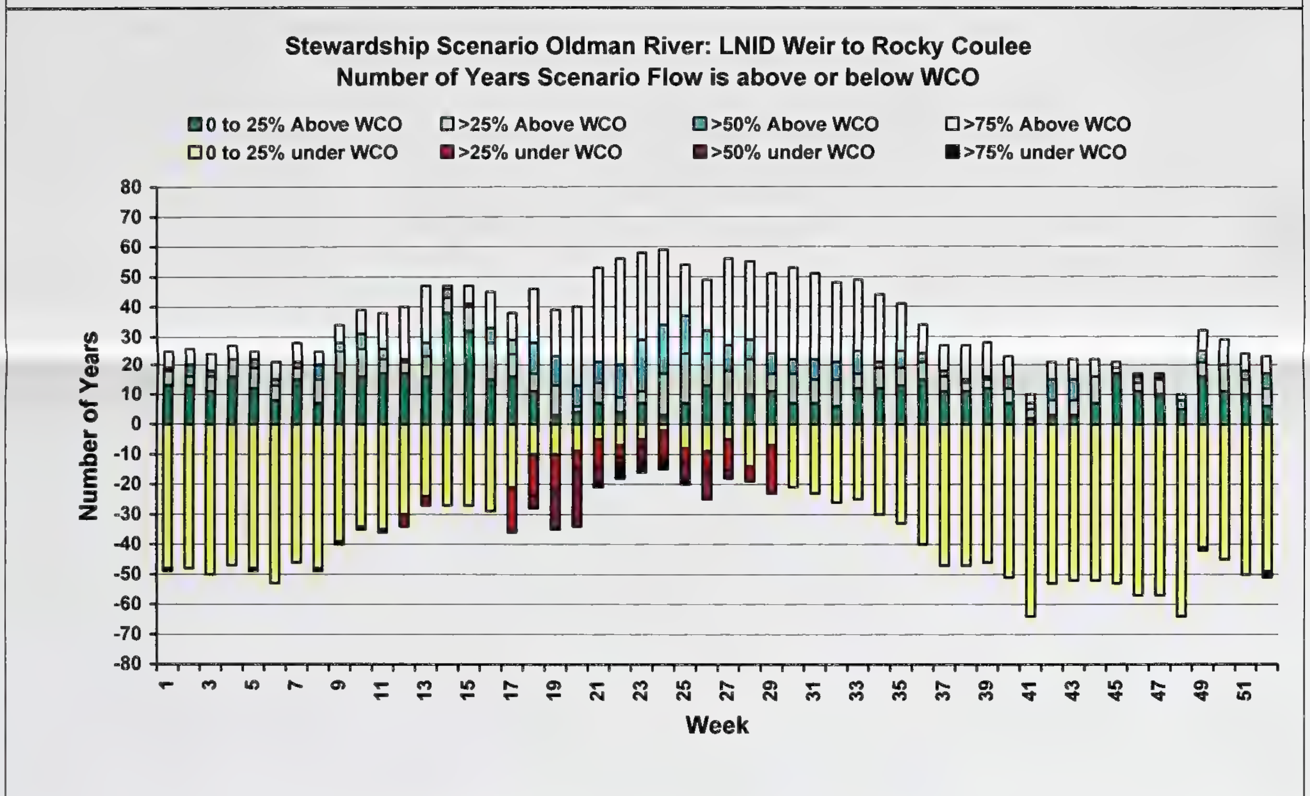


Figure WA 3 – Oldman WCO in Specific Reaches





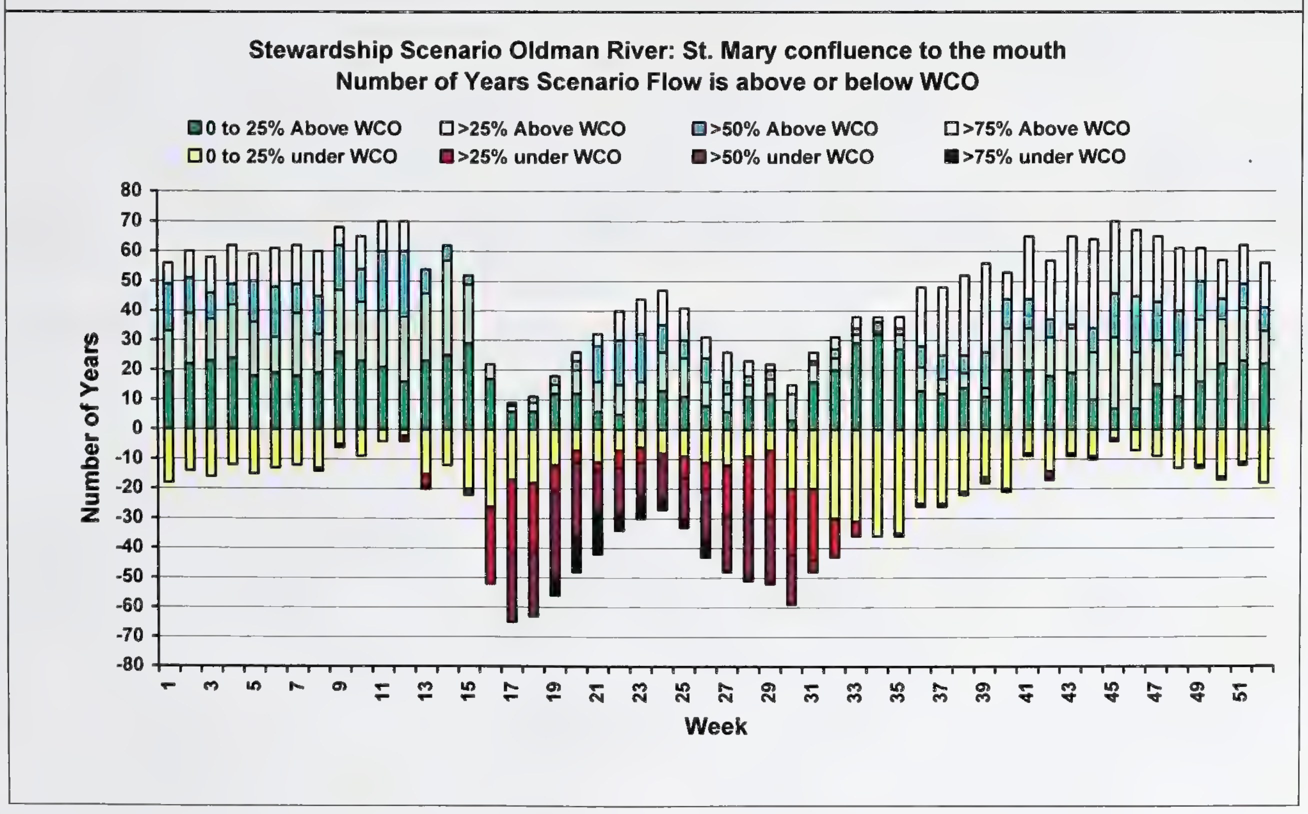


Table WA 2 – Drought Year Comparisons

(D is second year of back-to-back drought)

Delivery (% of natural flow)	Scenario	1932	1933	1937	1938	1942	1943	1945	1946	1950	1951	1978	1979	1985	1986	1989	1990	2002
		D		D		D		D		D		D		D		D		D
Apportionment	Base Case	64%	59%	50%	56%	75%	64%	59%	64%	57%	89%	67%	58%	53%	67%	55%	69%	
	Base Case Drought	51%	53%	52%	54%	53%	56%	59%	59%	48%	84%	56%	49%	50%	62%	51%	63%	48%
	Stewardship	65%	61%	50%	57%	76%	65%	59%	65%	58%	90%	69%	59%	54%	68%	56%	71%	
	Stewardship Drought	52%	54%	52%	55%	54%	57%	60%	60%	48%	85%	57%	49%	50%	63%	52%	64%	48%
	Development	59%	55%	51%	51%	72%	60%	56%	60%	51%	87%	64%	55%	51%	63%	52%	67%	
	Development Drought	48%	50%	49%	50%	52%	52%	55%	56%	47%	81%	52%	48%	48%	58%	51%	60%	46%

Non irrigation (% deficit to licence)	Scenario	1932	1933	1937	1938	1942	1943	1945	1946	1950	1951	1978	1979	1985	1986	1989	1990	2002
		D		D		D		D		D		D		D		D		D
Bow Juniors	Base Case	45%	47%	82%	51%	44%	53%	51%	48%	54%	40%	47%	60%	61%	47%	51%	46%	
	Base Case Drought	74%	48%	81%	53%	65%	54%	62%	48%	80%	41%	62%	63%	76%	48%	66%	46%	84%
	Stewardship	34%	37%	80%	40%	34%	43%	43%	39%	43%	31%	38%	54%	59%	38%	45%	36%	
	Stewardship Drought	75%	38%	78%	43%	61%	44%	59%	39%	79%	32%	60%	57%	75%	38%	65%	36%	84%
	Development	47%	49%	90%	56%	44%	55%	53%	48%	55%	41%	47%	64%	70%	48%	58%	47%	
	Development Drought	87%	62%	85%	58%	74%	55%	67%	48%	87%	42%	70%	67%	89%	51%	77%	48%	86%
Oldman Juniors	Base Case	22%	0%	68%	22%	0%	0%	27%	0%	0%	0%	0%	0%	52%	0%	35%	0%	
	Base Case Drought	81%	27%	47%	24%	29%	12%	75%	24%	28%	16%	43%	43%	77%	10%	75%	22%	73%
	Stewardship	20%	0%	72%	19%	0%	0%	26%	0%	0%	0%	0%	0%	49%	0%	23%	0%	
	Stewardship Drought	81%	25%	63%	22%	26%	5%	75%	23%	28%	15%	43%	39%	77%	8%	72%	22%	75%
	Development	45%	27%	88%	34%	24%	16%	49%	28%	26%	0%	23%	39%	77%	42%	75%	24%	
	Development Drought	90%	70%	85%	37%	77%	30%	78%	49%	85%	23%	77%	75%	90%	45%	87%	28%	87%
Southern Tribs Juniors	Base Case	0%	0%	47%	0%	0%	0%	36%	0%	0%	0%	2%	0%	3%	0%	0%	0%	
	Base Case Drought	44%	2%	68%	25%	18%	0%	65%	23%	0%	0%	36%	30%	11%	4%	27%	0%	65%
	Stewardship	0%	0%	45%	0%	0%	1%	36%	0%	0%	0%	2%	0%	0%	0%	0%	0%	
	Stewardship Drought	42%	2%	68%	25%	18%	0%	65%	23%	0%	0%	36%	30%	11%	0%	27%	0%	72%
	Development	0%	0%	47%	0%	0%	0%	38%	0%	0%	0%	2%	16%	23%	0%	0%	0%	
	Development Drought	43%	2%	70%	27%	18%	0%	65%	27%	2%	0%	38%	33%	11%	8%	27%	0%	67%
Milk Seniors	Base Case	2%	13%	21%	9%	6%	0%	10%	4%	5%	0%	0%	0%	10%	7%	3%	4%	
	Base Case Drought	8%	13%	10%	9%	4%	0%	0%	4%	4%	0%	2%	0%	19%	7%	3%	4%	30%

Irrigation deficits (mm)	Scenario	1932	1933	1937	1938	1942	1943	1945	1946	1950	1951	1978	1979	1985	1986	1989	1990	2002
		D		D		D		D		D		D		D		D		D
Bow Districts	Base Case	2	0	9	2	2	3	3	4	2	1	3	4	8	2	1	1	
	Base Case Drought	4	0	29	2	7	3	3	4	7	2	6	4	6	2	3	2	50
	Stewardship	2	0	4	2	1	2	3	4	2	1	3	4	5	2	0	1	
	Stewardship Drought	3	0	20	2	6	2	2	3	4	2	2	4	5	2	1	1	21
	Development	0	0	32	0	0	0	0	0	4	0	0	0	1	0	0	0	
	Development Drought	4	5	40	0	6	0	0	0	28	0	4	0	3	0	0	0	86
Bow Juniors	Base Case	15	6	174	0	4	6	30	19	17	0	0	119	139	0	92	16	
	Base Case Drought	206	6	235	1	173	6	81	21	162	0	169	119	190	0	138	16	242
	Stewardship	5	4	133	0	4	4	22	13	10	0	0	80	144	0	77	16	
	Stewardship Drought	216	4	215	1	166	4	80	14	153	0	178	80	178	0	144	16	253
	Development	19	13	295	2	6	12	50	32	21	0	0	147	180	2	154	19	
	Development Drought	281	28	279	3	219	10	120	37	250	0	190	152	248	2	210	19	288
Bow Seniors	Base Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Base Case Drought	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stewardship	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Stewardship Drought	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Development	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Development Drought	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oldman Districts	Base Case	0	0	1	0	0	0	0	0	0	0	0	0	35	0	1	0	
	Base Case Drought	149	0	78	0	1	0	131	0	0	0	28	0	8	0	105	1	147
	Stewardship	0	0	0	0	0	0	0	0	0	0	0	0	19	0	1	0	
	Stewardship Drought	135	0	70	0	0	0	116	0	0	0	25	0	7	0	82	1	164
	Development	0	0	45	1	0	2	1	0	3	0	0	16	123	1	24	1	
	Development Drought	195	32	182	1	18	2	105	0	65	0	102	40	105	1	152	1	223
Oldman Juniors	Base Case	2	0	137	0	0	0	8	0	0	0	0	0	171	0	23	0	
	Base Case Drought	305	0	67	1	69	0	268	5	30	0	209	0	211	0	309	1	199
	Stewardship	2	0	162	0	0	0	8	0	0	0	0	0	129	0	7	0	
	Stewardship Drought	313	0	138	1	57	0	267	5	30	0	213	0	222	0	281	1	210
	Development	103	28	319	44	6	32	99	74	5	0	2	145	313	109	226	1	
	Development Drought	335	119	342	42	257	9	293	152	321	0	272	208	334	112	361	3	331
Southern Tribs Districts	Base Case	9	11	29	10	7	11	26	6	5	1	2	11	10	5	9	11	
	Base Case Drought	124	21	122	23	22	12	130	18	16	1	101	21	18	13	136	17	246
	Stewardship	3	7	14	5	3	7	10	2	2	0	0	7	3	1	2	7	
	Stewardship Drought	117	11	106	8	10	7	103	6	7	0	80	10	8	1	112	8	235
	Development	4	7	21	8	3	8	15	2	2	0	1	9	9	2	3	8	
	Development Drought	132	12	131	10	19	8	131	8	9	0	100	15	25	8	144	10	245
Southern Tribs Juniors	Base Case	5	18	7	5	0	18	13	1	14	0	0	18	11	7	0	4	
	Base Case Drought	131	18	95	8	2	18	131	1	20	0	132	18	14	7	134	4	166
	Stewardship	5	18	7	5	0	18	8	1	14	0	0	18	11	7	0	4	
	Stewardship Drought	147	18	89	5	2	18	103	1	17	0	113	18	14	7	133	4	162
	Development	4	17	23	5	0	17	13	1	13	0	0	17	11	6	0	4	
	Development Drought	155	17	129	5	13	17	122	1	16	0	154	22	41	6	159	4	177
Southern Tibs Seniors	Base Case	29	83	32	27	0	90	7	16	53	0	0	92	39	21	1	17	
	Base Case Drought	70	83	109	27	13	90	72	16	79	0	49	92	54	21	115	17	115
	Stewardship	29	83	32	27	0	90	7	16	53	0	0	92	39	21	1	17	
	Stewardship Drought	70	83	109	27	13	90	72	16	79	0	49	92	54	21	115	17	115
	Development	29	83	32	27	0	90	7	16	53	0	0	92	39	21	1	17	
	Development Drought	70	83	109	27	13	90	72	16	79	0	49	92	54	21	115	17	115
Milk Juniors	Base Case	134	280	211	143	129	259	218	158	108	8	9	253	259	221	62	235	
	Base Case Drought	247	280	357	143	197	259	286	158	286	8	271	254	330	221	412	235	453

Figure WA 4 – Performance of Oldman Reservoir

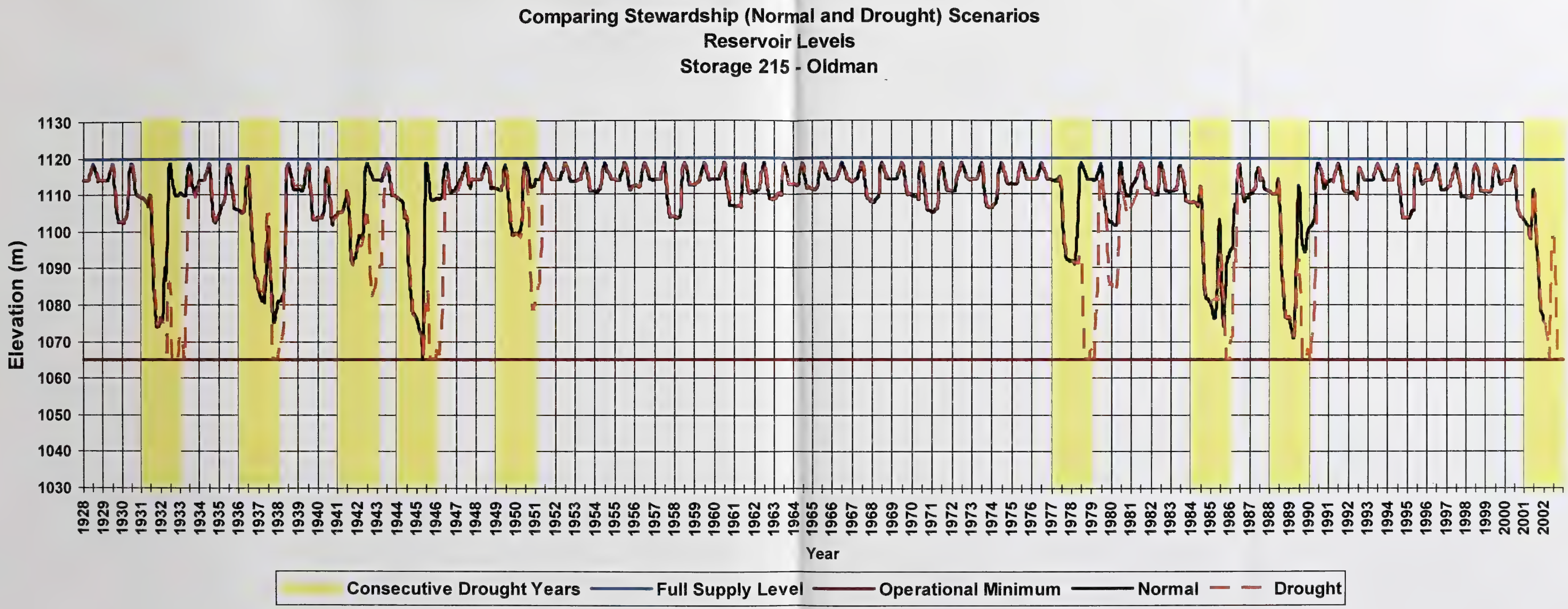
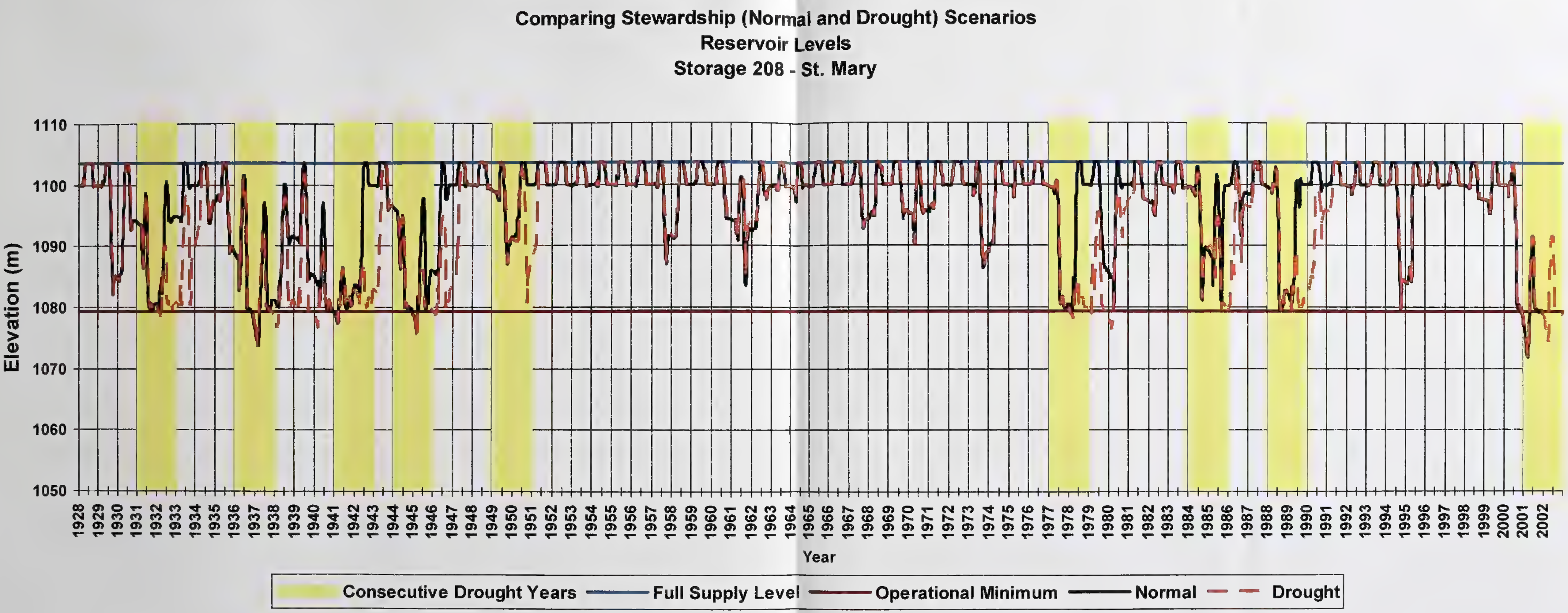


Figure WA 5 – Performance of St. Mary Reservoir



Water Quality

Key Assumptions and Differences of SSRP Scenarios

The Bow River Water Quality Model (BRWQM) system was applied to assess and compare the different water quality impacts related to the three scenarios defined for the SSRP study, i.e., Base Case, Stewardship, and Development. Figure WQ 5 summarizes the Bow River diversion and return flow quantity assumptions made for the three SSRP scenarios.

The major diversions from the Bow River within the BRWQM modelling domain are the water withdrawals by the City of Calgary, WID and BRID. Among the three SSRP scenarios, the Stewardship Case was assumed to be subjected to the least amount of flow diversion from the Bow River in comparison to the other two scenarios. It was assumed that the City of Calgary diverted only 38% of its licensed amount for the Stewardship Case, versus 98% of its licensed amount for the other two cases. The three scenarios are subjected to relatively similar amounts of irrigational flow diversions, with the annual diversions ranging between 5.5x105 ML/year (Stewardship Case), 5.9x105 ML/year (Base Case), to 6.3x105 ML/year (Development Case).

The major return flows to the Bow River within the BRWQM modelling domain are related to the City of Calgary and WID, i.e., the municipal WWTP effluents and the agricultural returns. Similar to what was assumed for the City of Calgary's diversion flows, the Stewardship Case was assumed to receive the least amount of return waters from the City of Calgary (1.6x105 ML/year) in comparison to the other two SSRP scenarios (3.7x105 ML/year for both Base and Development Cases). The amounts of irrigation returns are relatively similar between the three scenarios, with the annual returns ranging between 1.4Ex104 to 1.7x104 ML/year.

The BRWQM system was configured to account for the different Bow River diversion and return flows for each of the SSRP scenarios. The water chemistry conditions associated with the different boundary flows for the three scenarios were assumed to remain unchanged as the historical conditions defined during the model calibration/validation stage. This assumption might over-estimate the wastewater loadings discharged from the City of Calgary for the three scenarios, since the treatment technology has been advancing over the past decades. However, it is very difficult to carry out backward derivation of the historical effluent chemistry when assuming current treatment technology taking place historically. As a result, a more conservative approach was adopted for SSRP scenarios by assuming that the WWTP concentration profiles are following the historical recorded conditions.

On the other hand, the water quantity variations associated with the diversion and return flows under the three scenarios could result in substantially different strengths of waste loadings that would be discharged into the Bow River, resulting in very different water quality profiles in the Bow River.

Water Quality Parameters and Objectives

The primary water quality concerns for the Bow River include the protection of aquatic life within the Bow River, maintaining its recreational value, and safe-guarding downstream water uses. Relevant parameters of water temperature, dissolved oxygen (DO), total suspended solids (TSS) and nutrients (ammonia nitrogen, nitrate nitrogen, and total dissolved phosphorus-TDP) (see Table WQ 1) were selected in this modelling study to support the evaluation of the different potential risks associated with the water management plans for the three SSRP scenarios.

Figure WQ 5 - Bow River Water Diversions and Returns

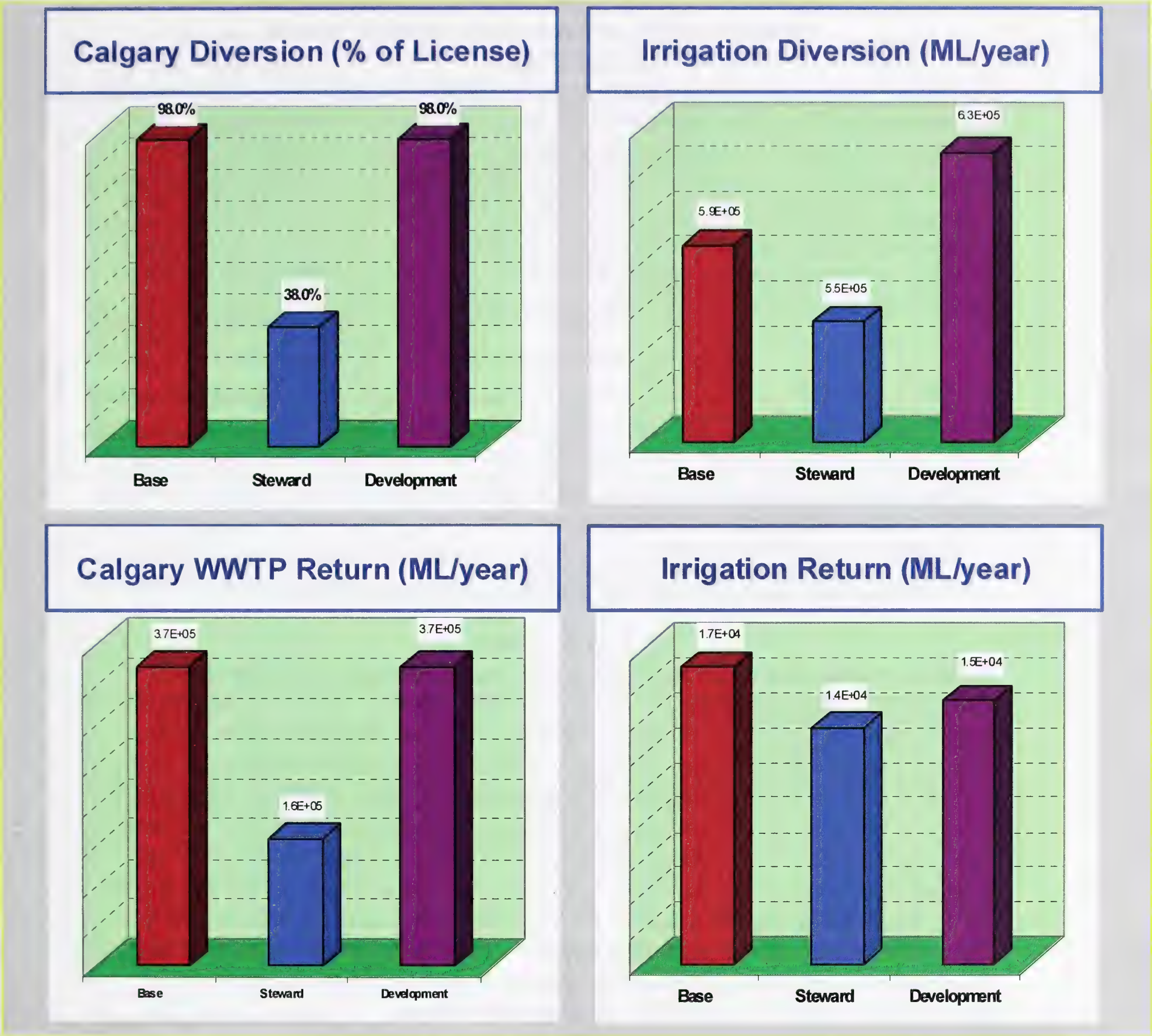


Table WQ 1
Selected Water Quality Parameters and Related BRBC Water Quality Objectives

		Central Bow River (Bearspaw Dam to Carseland)	Lower Bow River (Downstream of Carseland)
Temperature	°C	<24 °C at any time	<29 °C at any time
DO	mg/L	>5 mg/L for acute daily minimum	>5 mg/L for acute daily minimum
		>6.5 mg/L for chronic 7 day running average	>6.5 mg/L chronic 7 day running average
Ammonia	Mg_N/L	Lower of US EPA or 0.2 mg/L during growing season for aquatic vegetation	Lower of US EPA or 0.2 mg/L during growing season for aquatic vegetation
Nitrate	mg_N/L	1.5 mg/L during open water period	1.5 mg/L during open water period
TDP	mg_P/L	0.015 mg/L during growing season for aquatic vegetation	0.015 mg/L during growing season for aquatic vegetation
TSS[(1)]	mg/L	If background concentration (assuming 7 day exposure): <25 mg/L then conditions must not exceed a SEV value of 6; >25 mg/L conditions must not exceed an SEV value of 7; >250 mg/L conditions should not increase more than 10% above background level	If background concentration (assuming 7 day exposure): <25 mg/L then conditions must not exceed a SEV value of 6; >25 mg/L conditions must not exceed an SEV value of 7; >250 mg/L conditions should not increase more than 10% above background level

Note (1): SEV is calculated based on the equation proposed by Newcombe and Jensen (1996):

SEV (Scale of ILL Effect) = 1.0642 + 0.6068 * Ln(EP) + 0.7384 * Ln (TSS)

Where: EP = exposure period in hours; and

TSS = average TSS concentration for the exposure period in mg/L.

Background TSS concentrations was represented by simulated TSS concentrations just below Bearspaw Dam.

The Bow River Water Quality Objectives (WQO) developed by the Bow River Basin Council (BRBC, 2008) were also used to support the evaluation and comparison of the water quality risks related to the three scenarios. The Bow River WQOs were reach-specific water quality objectives and targets developed to ensure the protection of the natural or existing environment of each Bow River reach. BRBC divided the entire Bow River into four sub-reaches, which are Bow River above park boundary, Bow River below park boundary, Bow River Central, and Bow River Lower. A unique set of WQOs was established to protect each Bow River sub-reach. Two of the Bow River sub-reaches fall within the BRWQM modelling domain for this SSRP study, i.e., the Bow River Central (from Bearspaw to Carseland) and the Bow River Lower (from Carseland to its outlet). The detailed water quality objectives for the selected water quality parameters are listed in Table WQ 1 for each of the two Bow River reaches.

Results

For each SSRP scenario, the BRWQM was configured accordingly and then a model run was performed for a 12 year period (from 1990 to 2001) of continuous simulation. This long simulation period allows the modelling results to account for the varying water quality conditions under different climate conditions. The BRWQM simulation results for the following Bow River nodes were selected and assessed against the BRBC WQOs for the relevant Bow River reach:

- Stiers Ranch at Central Bow River reach;
- Carseland at Central Bow River reach;
- Bassano Dam at Lower Bow River reach.

An exceedance of a selected water quality parameter is considered to occur when the BRWQM predicted value is beyond the BRBC specified WQO range within the evaluation period. An exceedance frequency for a selected water quality parameter is calculated based on the number of days the predicted values are beyond the WQO range, and the total number of simulated days within the evaluation period. For each SSRP scenario, the exceedance frequencies of the BRBC WQOs for the selected water quality parameters were determined for all the three assessment nodes based on the BRWQM predictions. All the results were summarized in Tables WQ 2 to WQ 8, and are discussed as below.

Water Temperature

Water temperature is a conventional water quality indicator and typically varies appreciably between seasons for the Bow River water. Water temperature could become a concern for northern cold-water fish in the Bow River during the summer season when air temperature peaks. However, the BRWQM water temperature simulation results (Table WQ 2) suggest that water temperature exceedance of the BRBC WQO limits is unlikely to occur in the Bow River for all the three SSRP scenarios.

Table WQ 2
Water Temperature Exceedance Frequencies

	Evaluation Criteria	Assessment Node	Water Temperature Exceedance		
			Base Case	*Stewardship Case*	*Development Case*
Central Bow River	<= 24°C anytime	*Stiers Ranch*	0%	0%	0%
		Carseland	0%	0%	0%
Lower Bow River	<= 29°C anytime	*Bassano*	0%	0%	0%

Total Suspended Solids

Excess TSS concentrations could affect fish productivity and is also considered an important water quality indicator for the Bow River. The BRBC WQOs for TSS are based on the severity of ill effects (SEV) defined by Newcombe and Jensen (1996, see Table WQ1) for chronic TSS exposure effects.

As indicated in Table WQ 3, the predicted TSS exceedance frequencies among the three SSRP scenarios are very consistent, with the percentage days of exceedance ranging between 13 to 28% for the three selected assessment nodes. Spatially, the TSS exceedance frequencies for the three scenarios all go up from central Bow River to

lower Bow River. The elevated TSS exceedance at lower Bow River reach is likely related to the fact that the Bow River receives more agricultural related non-point source flows within this range of the Bow River, typically associated with higher levels of TSS.

Table WQ 3
Total Suspended Solids Exceedance Frequencies

	Evaluation Criteria	Assessment Node	Total Suspended Solids		
			Base Case	***Stewardship Case***	***Development Case***
Central Bow River	see Note 1 of Table 1	***Stiers Ranch***	13%	13%	13%
		Carseland	27%	26%	27%
Lower Bow River		***Bassano***	28%	27%	28%

Nutrients

The nutrients included in this exceedance assessment are ammonia nitrogen, nitrate nitrogen, and total dissolved phosphorus (TDP). Ammonia can be toxic to aquatic life depending on its concentration. However, the major concern of ammonia nitrogen in the Bow River is that ammonia acts together with nitrate and dissolved phosphorus as the readily available nutrient sources to stimulate the excessive growth of aquatic vegetations within the Bow River. The over-growth of aquatic vegetations can introduce reduced or even depleted DO conditions, which will ultimately affect the fish survival in the Bow River. The exceedance assessment of ammonia nitrogen, nitrate nitrogen, and TDP concentrations are presented in Tables WQ 4, 5 and 6.

Table WQ 4
Ammonia Nitrogen Exceedance Frequencies

	Evaluation Criteria	Assessment Node	Ammonia Nitrogen Exceedance		
			Base Case	***Stewardship Case***	***Development Case***
Central Bow River	**Lower of US EPA or <=0.2 mg/L**	***Stiers Ranch***	83%	37%	81%
		Carseland	55%	20%	53%
Lower Bow River		***Bassano***	35%	15%	34%

Table WQ 5
Nitrate Nitrogen Exceedance Frequencies

	Evaluation Criteria	Assessment Node	Nitrate Nitrogen Exceedance		
			Base Case	***Stewardship Case***	***Development Case***
Central Bow River	<=1.5 mg/L	***Stiers Ranch***	17%	0%	15%
		Carseland	16%	0%	14%
Lower Bow River		***Bassano***	16%	0%	14%

Table WQ 6
Total Dissolved Phosphorus Exceedance Frequencies

	Evaluation Criteria	Assessment Node	Total Dissolved Phosphorus Exceedance		
			Base Case	*Stewardship Case*	*Development Case*
Central Bow River	<=0.015 mg/L	*Stiers Ranch*	99%	69%	98%
		Carseland	98%	57%	97%
Lower Bow River		*Bassano*	76%	39%	75%

The predicted concentrations of ammonia nitrogen for the Stewardship Case have much lower percentage of exceedance frequency than for the Base and Development Cases. The ammonia exceedance frequencies for the Stewardship Case are ranging between 15% and 37% at the three assessment nodes. The predicted ammonia nitrogen concentrations are very similar for the Base and Development Cases with percentages of exceedance more than two times higher for the Stewardship Case at each of the assessment nodes. The primary loading sources of ammonia in the Bow River are the effluent discharges from the City of Calgary's wastewater treatment plants. For the Stewardship Case, the WWTP return flows from Calgary are reduced to about 50% of the levels for the other two scenarios, which would bring in much lower ammonia concentrations in the Bow River as compared to the other two cases.

Table WQ 4 also shows that the ammonia exceedance frequencies decline appreciably from the upstream node to the downstream node for all the scenarios. Taking the Base Case as an example, the predicted ammonia exceedance frequency at the Stiers Ranch node is 83%, but decreases to 55% at the Carseland node and 35% at Bassano node. The spatially gradual decrease of ammonia concentrations is explained by the fact that ammonia is not only taken up by vegetations along the travel of the flow, but also undergoes significant bio-chemical oxidation decay after being released from the City's WWTPs.

The major loading sources of nitrate nitrogen and TDP are also Calgary's WWTPs for the Bow River. Nitrate and TDP show similar exceedance spatial distribution patterns as ammonia for all the scenarios. The predicted nitrate concentrations have no exceedance occurrences at the three assessment nodes for the Stewardship Case, while they cause 14 to 17% of exceedance for the other two scenarios.

Based on the model predictions, the exceedance frequencies of TDP are ranging between 39 to 69% for the Stewardship Case, but go up to 75 to 99% for the other two cases. The predicted TDP concentrations exceed the BRBC WQO limits by almost 100% during the growth seasons at the Stiers Ranch node for the Base and Development Cases. A key point that needs to be noted here is that TDP concentration is not directly adverse to fish health, it affects fish survival via stimulating excessive vegetation growth which could potentially result in DO depletion. However, aquatic vegetation growth is

not only limited by nutrients, but also by other environmental factors such as water temperature, flow velocity, and solar radiation. In other words, when the phosphorus levels in the river rise above a certain level, vegetation growth rate will be controlled by environmental factors other than phosphorus concentration in the water. Accordingly, the exceptionally high percentages of predicted TDP exceedance for the Base and Development Cases would not necessarily link to DO depletion and high fish mortality.

Phosphorus was identified as one of the key nutrient parameters that triggered the over-growth of vegetation and low DO conditions in the Bow River (Golder 2004a, 2004b). Figure WQ 6 compares the three contour maps of BRWQM simulated total phosphorus (TP) concentrations that could potentially have happened on September 14th, 2001 for the three SSRP scenarios. These maps suggest that phosphorus concentrations are insignificant in the Bow River upstream of Calgary. The two most significant phosphorus plumes shown in these maps are located just downstream of the two WWTPs operated by the City of Calgary. The results show that these plumes gradually get dispersed with the ambient water as they travel downstream. The contour maps also show other phosphorus loadings that get discharged into the Bow River. However, the magnitudes of these loadings are much less significant than the ones from Calgary's WWTPs. The contours also illustrate that the phosphorus plumes for the Stewardship Case are much less significant when compared with the other two cases. This is explained by the assumption that the annual return flow from the City of Calgary for the Stewardship Case was set to be only about 50% of what it was for the other two cases.

Figure WQ 6
BRWQM Predicted Total Phosphorus Distribution between Bearspaw Dam and Bassano Dam

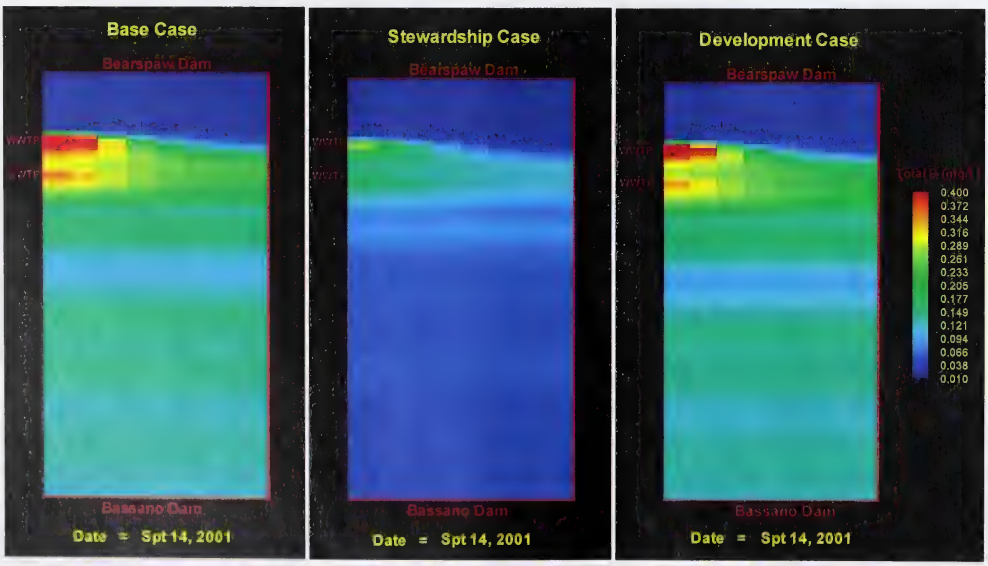
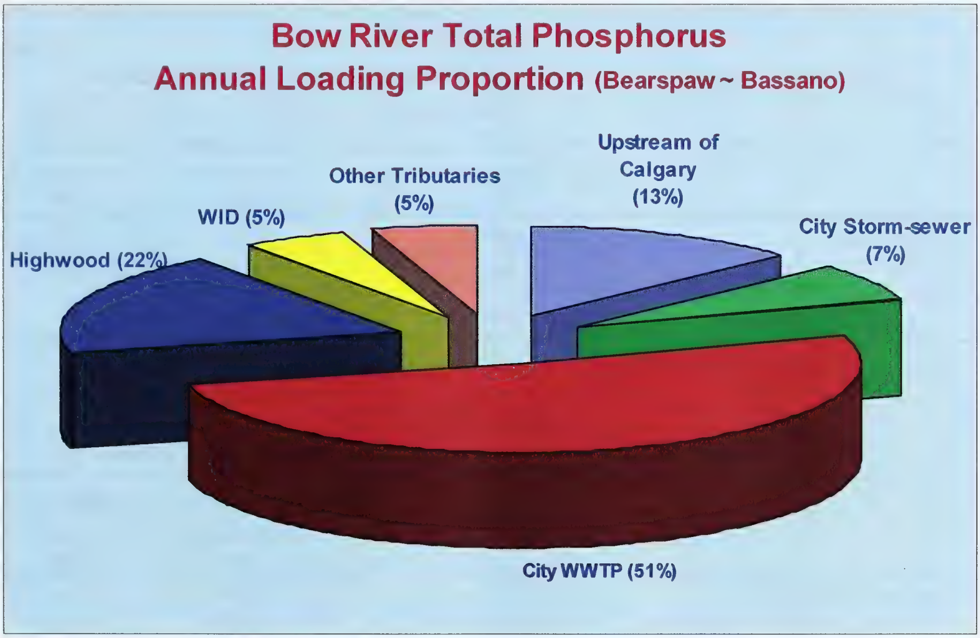


Figure 7 displays the distributions of the total phosphorus loadings from all the sources within the SSRP modelling domain, based on the historical total phosphorus data. The City of Calgary accounts for more than 60% of the TP loadings into the Bow River, primarily from its WWTPs. The control of effluents from Calgary's WWTP, as given in the Stewardship Case, could be the most effective approach to bring down the phosphorus concentrations in the Bow River.

Figure WQ 7
Total Phosphorus Annual Loading Proportions between Bearspaw Dam and Bassano Dam



Dissolved Oxygen

Dissolved oxygen is regarded as the key water quality parameter relative to the fate of aquatic life in the Bow River. If DO concentration becomes too low, aquatic life is put under stress. Dissolved oxygen normally varies with a seasonal pattern in the Bow River. Dissolved oxygen is usually high during the winter period due to low water temperature and slow bio-chemical reactions, whereas low dissolved oxygen typically occurs during the summer period as a result of massive aquatic plant respiration. If aquatic vegetation becomes very abundant in the river, DO can fall to levels that may adversely affect fish health. Under extreme conditions, fish kills can occur.

BRBC specified two categories of DO concentration objectives for the Bow River. One is a chronic DO objective that requires the average DO conditions over any 7 day period to be higher than 6.5 mg/L. The other is an acute objective that requires any instantaneously measured DO to be above 5.0 mg/L.

Tables WQ 7 and 8 present the predicted DO exceedance frequencies against these two objectives for all the scenarios. The predicted DO concentrations do not show any exceedance of the chronic DO objective at each assessment node for the three scenarios (Table WQ 7), which suggests that there is no major chronic DO issue for the three scenarios. However, exceedance of the acute DO objective is observed for all the three SSRP scenarios, based on the predicted DO concentrations at the three assessment nodes. For the Stewardship Case, the predicted DO concentrations at the Stiers Ranch node exceed the acute DO objective by only 0.1% of the whole evaluation period. On the other hand, the exceedance frequencies of acute DO objective go up to as high as 6% at the Stiers Ranch node for both the Base and Development Cases.

Table WQ 7
Chronic Dissolved Oxygen Exceedance Frequencies

	Evaluation Criteria	Assessment Node	Dissolved Oxygen Exceedance - chronic (days)		
			Base Case	*Stewardship Case*	*Development Case*
Central Bow River	>=6.5 mg/L	*Stiers Ranch*	0%	0%	0%
		Carseland	0%	0%	0%
Lower Bow River		*Bassano*	0%	0%	0%

Table WQ 8
Acute Dissolved Oxygen Exceedance Frequencies

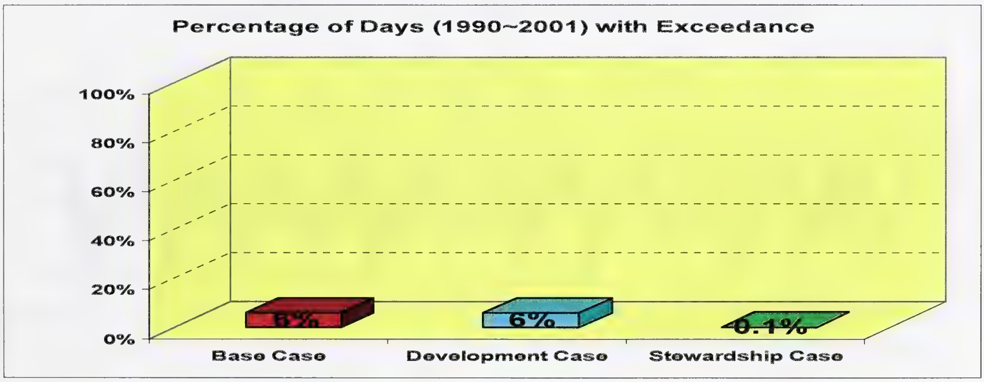
	Evaluation Criteria	Assessment Node	Dissolved Oxygen Exceedance - acute (days)		
			Base Case	*Stewardship Case*	*Development Case*
Central Bow River	>=5.0 mg/L	*Stiers Ranch*	6%	0.1%	6%
		Carseland	0.5%	0%	0.5%
Lower Bow River		*Bassano*	0%	0%	0%

The BRWQM results also indicate that the three scenarios demonstrate a similar spatial pattern of acute DO exceedance such that higher frequencies of acute DO exceedance would more likely occur around the Bow River reach within the City of Calgary limit. The acute DO exceedance frequencies would drop quickly as the water travels downstream and would become very negligible for the lower Bow River reach. The spatial pattern of DO exceedance is related to the fact that the majority of the nutrient loading for the Bow River is from the City of Calgary, especially its WWTPs. There are also numerous nutrient loading sources downstream of the City, but their magnitudes are less significant, and the DO levels could gradually be recovered via a natural re-aeration process as the flow travels downstream.

Figure WQ 8 shows the predicted DO time-series graphs, as well as the calculated acute DO exceedance probabilities and the predicted Bow River flows at the Stiers Ranch node for the three scenarios. The predicted DO values that are lower than 5 mg/L are expected to occur much less frequently for the Stewardship Case than for the other two cases. This demonstrates that minimizing the water quality risks in the Bow River can be achieved through effective control of the nutrient loadings discharged from the City of Calgary's WWTPs, as given in the water management plans employed for the Stewardship Case. The figures also indicate that extremely low DO condition is more likely to occur during dry events. For example, the extreme low DO conditions (<2mg/L) for the Base Case at Stiers Ranch were predicted to occur during year 2000 and 2001, when the summer flows in the Bow were the lowest during the 12 year simulation period.

Figure WQ 8
BRWQM Predicted Dissolved Oxygen and Flows at Bow River Stiers Ranch Site

(a) Percentages of Acute DO Exceedance



(b) Base Case

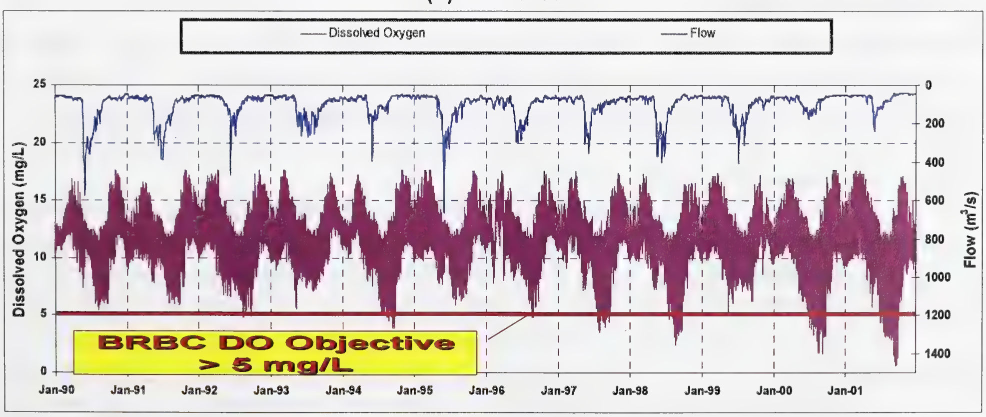
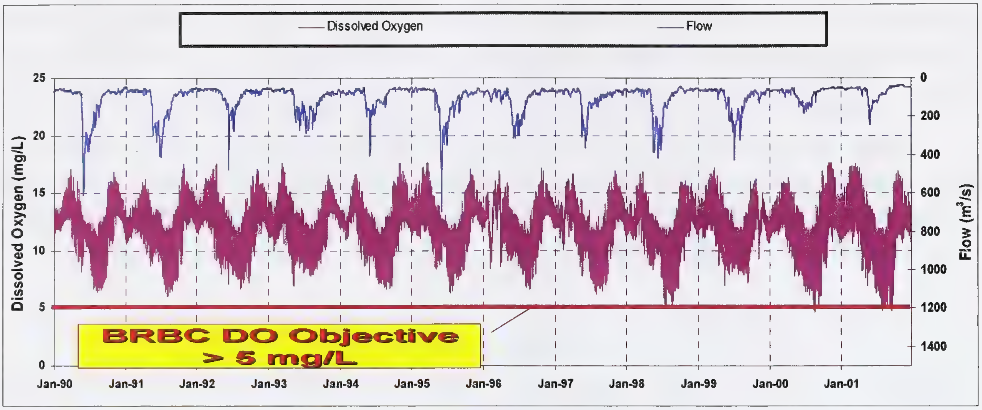
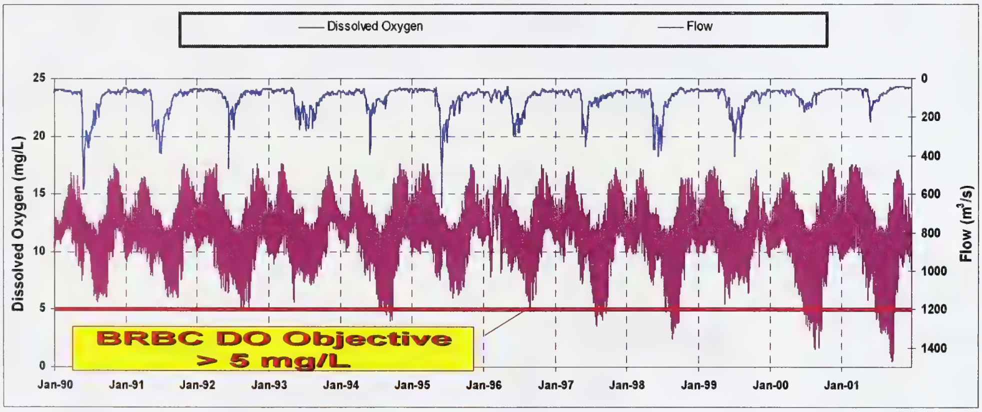


Figure WQ 8 (continued)

(c) Stewardship Case



(d) Development Case



Summary and Findings

An integrated BRWQM system was applied to simulate the changes of water quality conditions for the three SSRP scenarios. The simulated water quality results and the BRBC-developed WQOs were applied to assess the water quality risks associated with each of the SSRP scenarios. Based on the analysis by this study, a number of key findings are derived and summarized below.

- The primary water quality risk in the Bow River is dissolved oxygen, as it is directly related to fish health in the Bow River. Nutrients in the Bow River do not directly affect fish health, but can depreciate the river water quality conditions through encouragement of excessive growth of aquatic vegetation, which can then introduce inferior DO conditions for fish survival. The model predictions reveal that acceptable DO conditions could generally be sustained in the Bow

River under the Stewardship Case. However, much less acceptable DO conditions and an elevated exceedance probability of DO objectives are expected to occur under both the Base and Development Cases.

- Phosphorus was identified as one of the key nutrient parameters that triggered the over-growth of vegetation and low DO conditions in the Bow River. The primary phosphorus loading for the Bow River is from the City of Calgary's WWTPs. Proper management of the total loadings from these WWTPs, as given in the Stewardship Case, is the critical measure for controlling the water quality risks in the Bow River;

- Excess TSS concentrations could also affect fish productivity. The predicted TSS exceedance frequencies among the three SSRP scenarios are very consistent across the three SSRP scenarios, and are mainly related to the non-point source loadings into the Bow River.

- High water temperature could also potentially become a risk for fish health. The model predictions indicate that the probability of the Bow River water temperature exceeding the BRBC WQO limits is very unlikely for the three SSRP scenarios.

All the SSRP scenario simulation results are based on the conditions for the Bow River between Bearspaw Dam and Bassano. Caution needs to be applied when extrapolating the conclusions of these three SSRP scenarios from this study area to the other areas of the Southern Region.

<u>Hydrological Drought Scenarios</u>

Hydrological drought normally exerts adverse influences on the water quality conditions in the Bow River. Hydrological drought would bring in decreased amounts of natural flows from upstream of the Bow River, and is expected to result in worse water quality conditions due to the river's reduced assimilation capacity for the waste loadings discharged from municipalities or agricultural developments. The BRWQM system was configured to simulate the water quality changes under a back–to-back drought event presumed to occur in the Bow River. The method of how to configure the BRWQM to simulate the back-to-back drought event and the evaluation of the simulated results are discussed in detail below.

Water Quality Model Configuration for Drought Scenarios

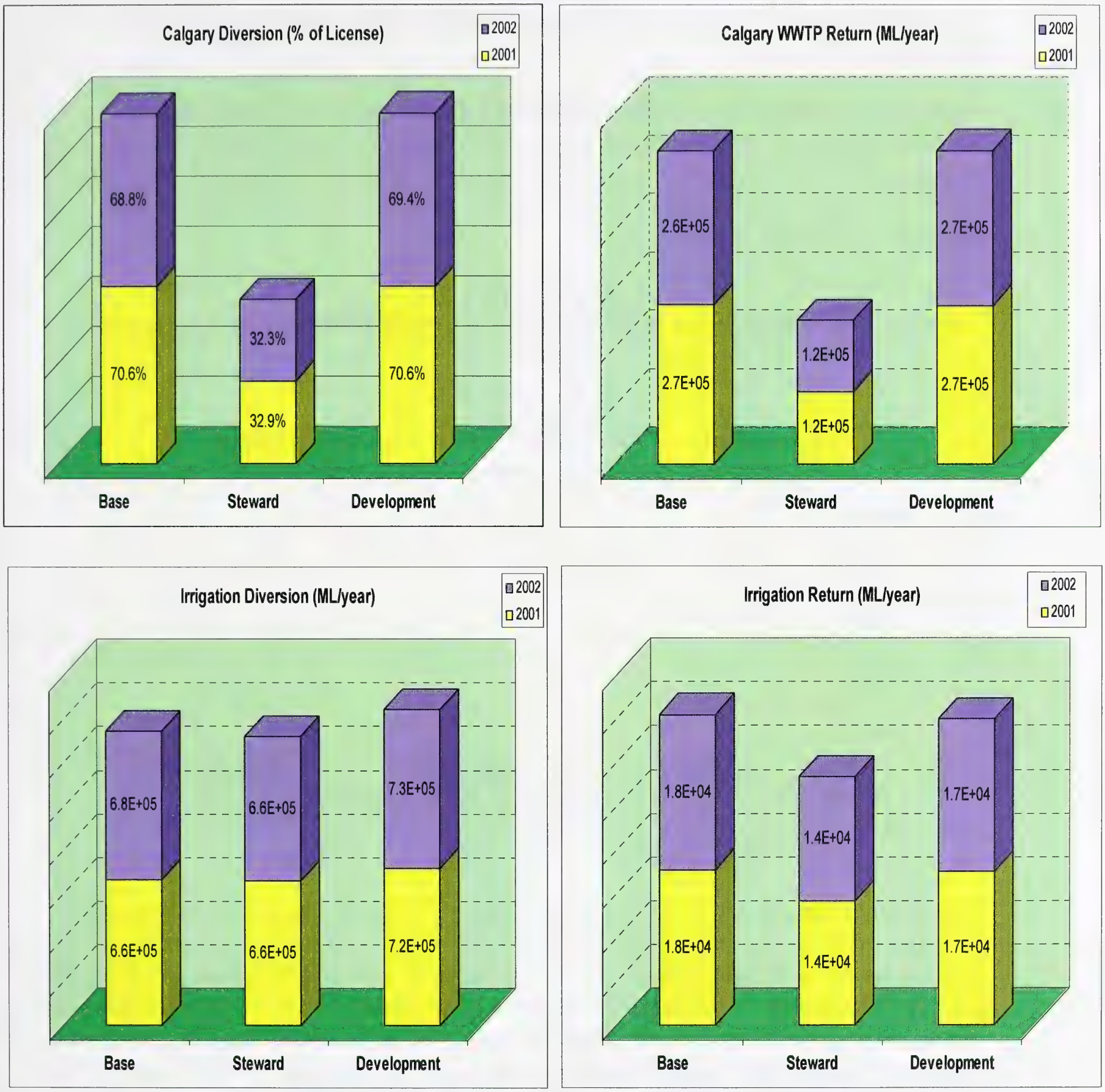
The Bow River historical flow data were analyzed to identify any drought events during the period between 1990 and 2001. In the end, the 2001 hydrological condition was selected as the most representative drought event within the 12 year simulation period.

A major concern from the public is what the water quality impact would be if a back-to-back drought event occurred in the Bow River Basin. To simulate a back-to-back

drought event, it was assumed that similar dry weather and flow conditions would repeat for the Bow River Basin in year 2002; to do this, the BRWQM was expanded to simulate an additional year, 2002. Figure WQ 9 summarizes the assumed Bow River diversion and return flow quantities for the three SSRP back-to-back scenarios, which indicates similar Bow River return and diversion flows between the two drought years. However, some differences do exist if comparing the amount of the Bow River diversions and returns during drought years against the long term annual averaged amounts (shown in Figures WQ 5 and WQ 9). In short, under the drought condition, the City of Calgary is assumed to divert and return only 70-85% of the Bow River water it normally diverted under the long term averaged conditions for the three SSRP scenarios. On the other hand, the irrigation diversions and returns were projected to go up by 10 to 20% under the drought condition for the three SSRP scenarios.

Other BRWQM boundary flow conditions for year 2002 were hypothesized to be the same as what were defined for year 2001 for each of the three SSRP scenarios; the meteorological conditions for year 2002 were also assumed to be repeating the conditions for year 2001. The BRWQM set-ups for the three SSRP scenarios were expanded temporarily to year 2002 to allow for the simulations of hypothetical back-to-back drought events for the three SSRP scenarios.

Figure WQ 9
Bow River Water Diversions and Returns for SSRP Drought Scenarios



Results and Discussion

The back-to-back drought scenario simulation results were assessed similarly by comparing the BRWQM simulation results and the relevant Bow River WQOs to determine the potential water quality risks associated with drought conditions (see Figures WQ 10 to 16).

Figure WQ 10 shows the predicted temperature exceedance results under drought conditions. Based on the results, the reach specific Bow River water temperature objectives are not likely to be exceeded for any of the three SSRP scenarios. In other words, the water temperature related fish health risk is minimal under the drought condition for all three SSRP scenarios.

Figure WQ 10
Water Temperature Exceedance for SSRP Drought Scenarios

(a) Stiers Ranch Site

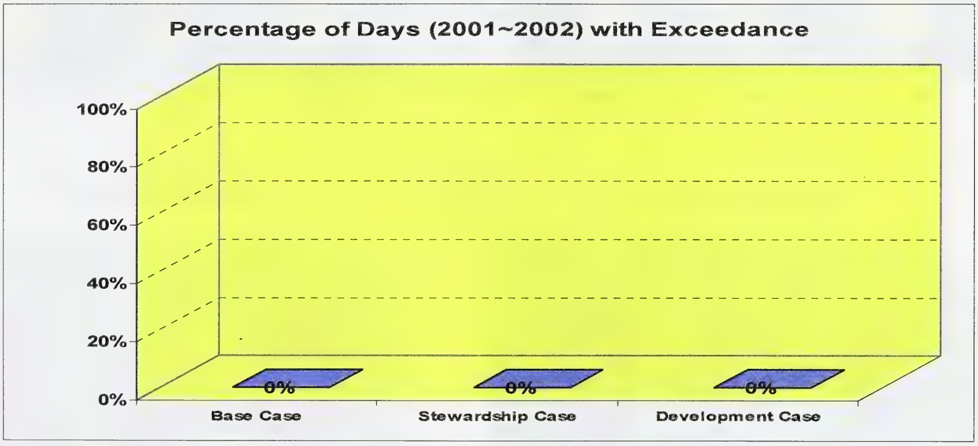
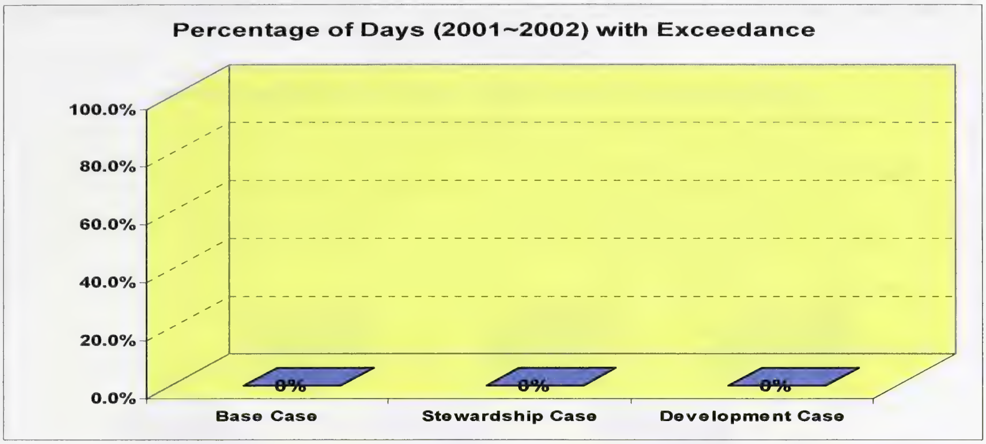
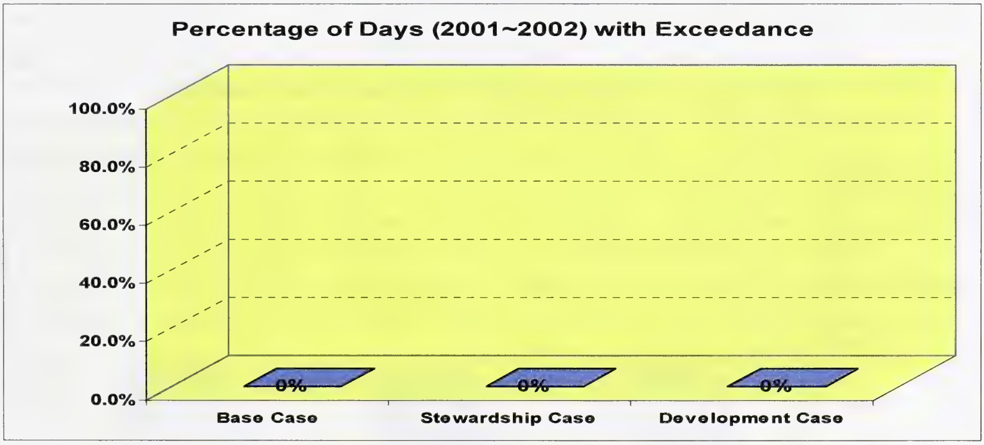


Figure WQ 10 (continued)

(b) Carseland Site



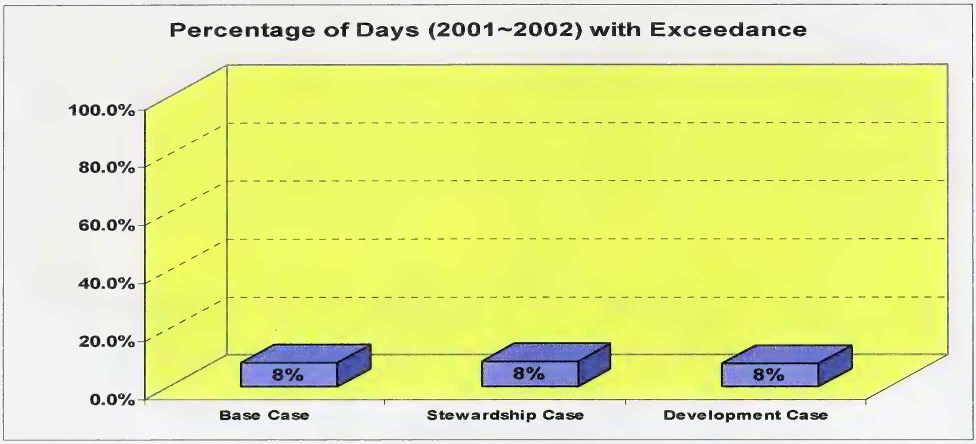
(c) Bassano Site



The exceedance frequencies of TSS decrease by about 5% for the drought scenarios at all the assessment nodes (See Figure WQ 11), if compared with the results from the original long term scenario simulations (Table WQ 3). For example, the TSS exceedance level at Stiers Ranch is determined to be around 13% based on the long-term Base Case simulation, but goes down to be only about 8% under the drought Base Case condition. The improved TSS concentrations under the drought condition is mainly due to the fact that the major TSS loading sources, such as storm water inflows, would become much less significant under drought conditions.

Figure WQ 11
Total Suspended Solids Exceedance for SSRP Drought Scenarios

(a) Stiers Ranch Site



(b) Carseland Site

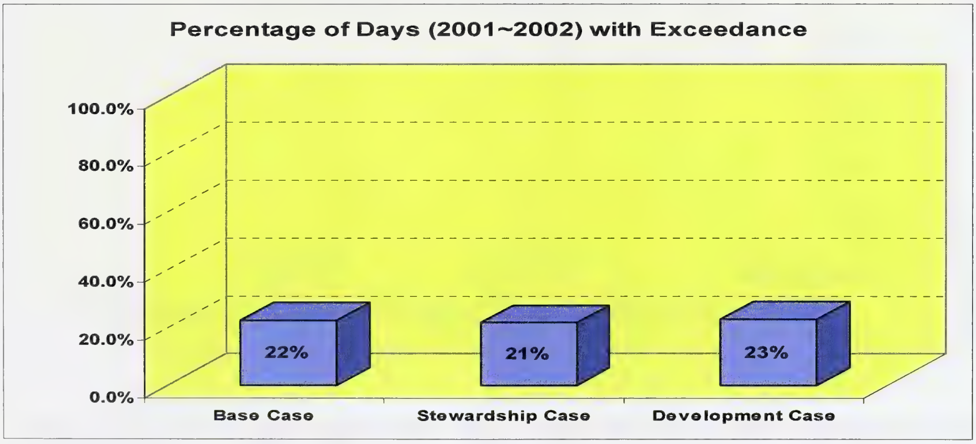
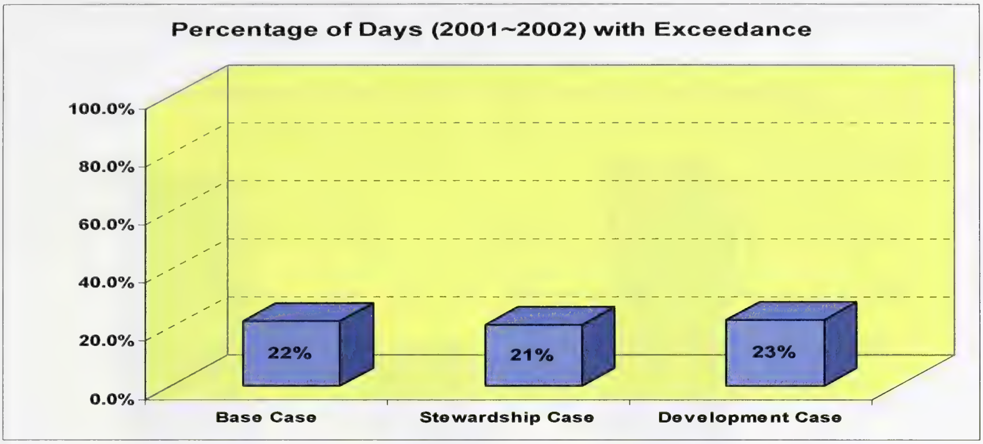


Figure WQ 11 (continued)

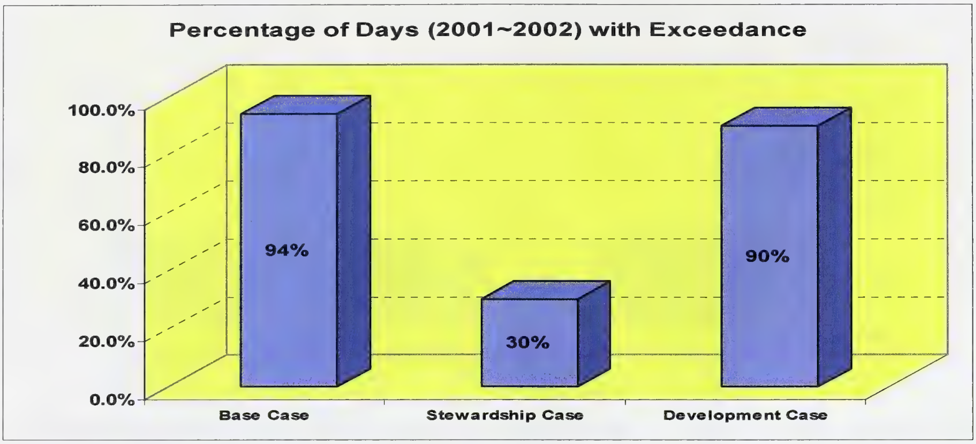
(c) Bassano Site



The exceedance frequencies of ammonia are expected to increase by 10% for the Stiers Ranch node under the drought condition for both the Base and Development scenarios (Figure WQ 12), if compared with the results based on the long-term scenario simulations. The elevated ammonia exceedance is related to less ambient Bow River water available to attenuate the major ammonia loadings discharged by the City of Calgary under the drought conditions for these two scenarios. However, because less water diversions and returns from the City of Calgary is assumed for the Stewardship Case, the predicted ammonia concentrations have reduced levels of exceedance under the drought condition at the Stiers Ranch node. For the Bow River lower reach assessment nodes, the ammonia exceedance frequencies become less significant for all the drought scenarios. This is mainly due to less amounts of boundary loadings from this range of river under the drought condition (for example, the loadings from Highwood River), as well as such river self remedy functions as the bio-chemical oxidation along the travel of the flow away from the City Limit.

Figure WQ 12
Ammonia Nitrogen Exceedance for SSRP Drought Scenarios

(a) Stiers Ranch Site



(b) Carseland Site

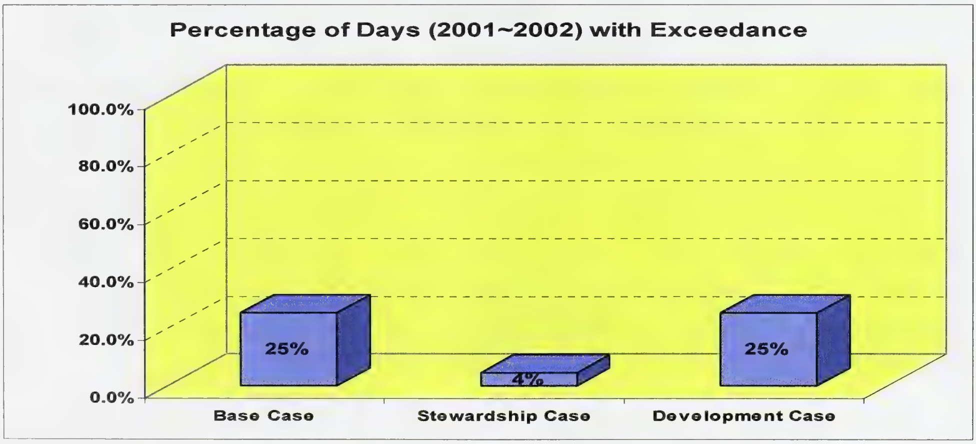
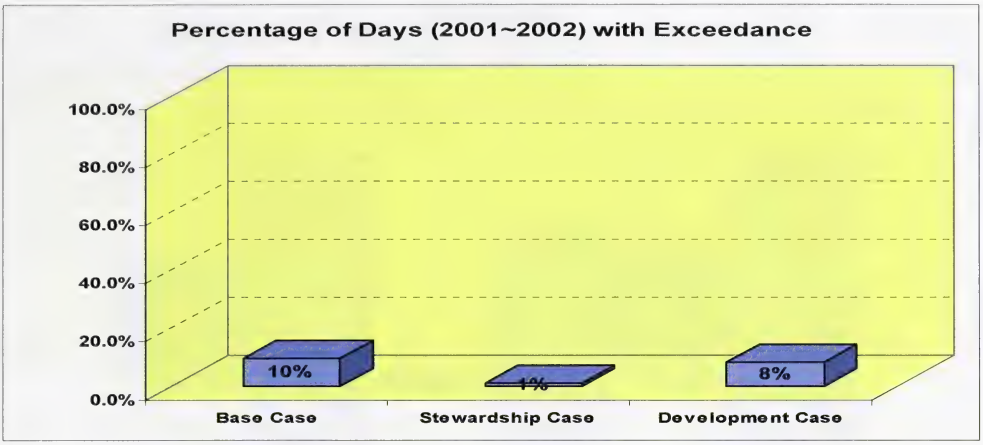


Figure WQ 12 (continued)

(c) Bassano Site



The exceedance frequencies of nitrate are appreciably higher under the drought condition for both the Base and Development scenarios (see Figure WQ 13), if compared with the results based on the long-term scenario simulations. The elevated nitrate exceedance is related to less ambient Bow River water available to attenuate the major nitrate loadings discharged by the City of Calgary under the drought conditions for these two scenarios. However, the nitrate exceedance remains negligible under drought condition for the Stewardship scenario, due to less Bow River diversions and return flows assumed for this scenario.

Figure WQ 13
Nitrate Nitrogen Exceedance for SSRP Drought Scenarios

(a) Stiers Ranch Site

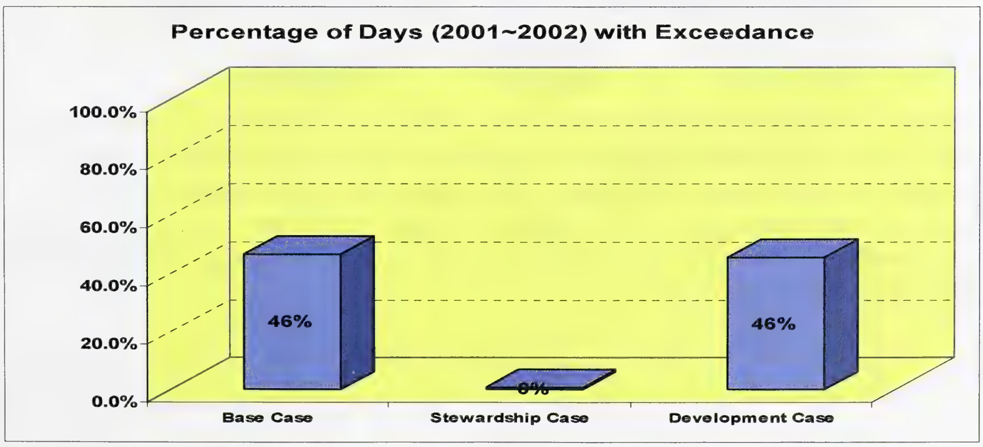
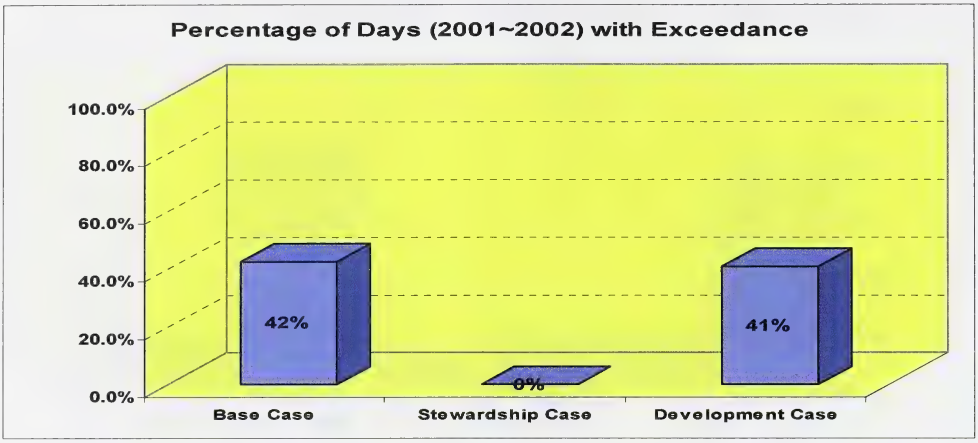
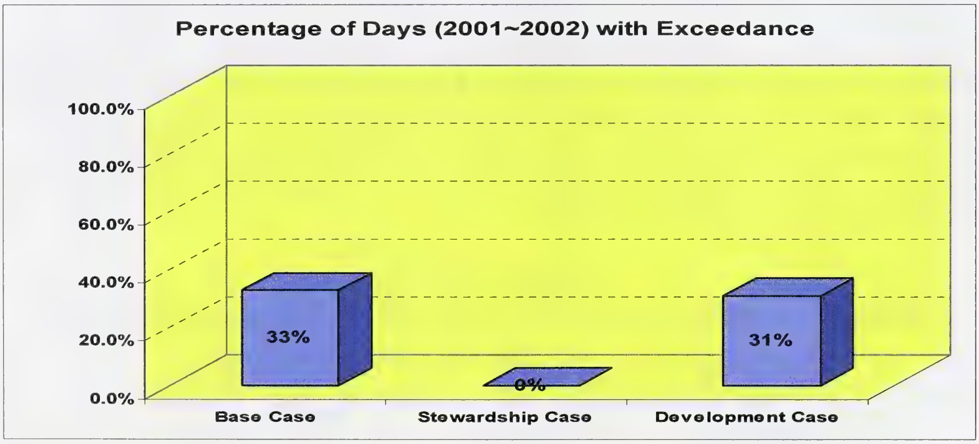


Figure WQ 13 (continued)

(b) Carseland Site



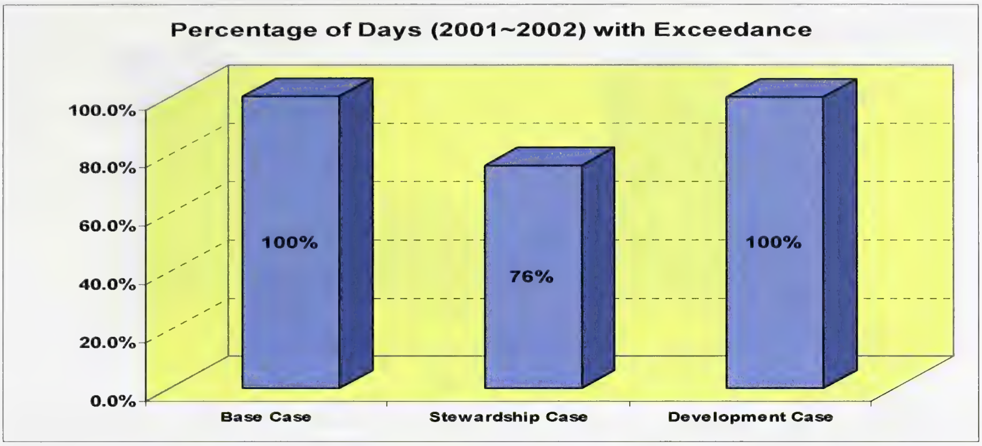
(c) Bassano Site



Similar to nitrate, the exceedance frequencies of dissolved phosphorus are generally higher at the Stiers Ranch node under drought conditions than the corresponding exceedance results from the long-term SSRP scenario simulations (Figure WQ 14). Under drought condition, the TDP exceedance frequencies for the Stewardship scenario are considerably lower than the results for both Base and Development scenarios at the three assessments nodes.

Figure WQ 14
Total Dissolved Phosphorus Exceedance for SSRP Drought Scenarios

(a) Stiers Ranch Site



(b) Carseland Site

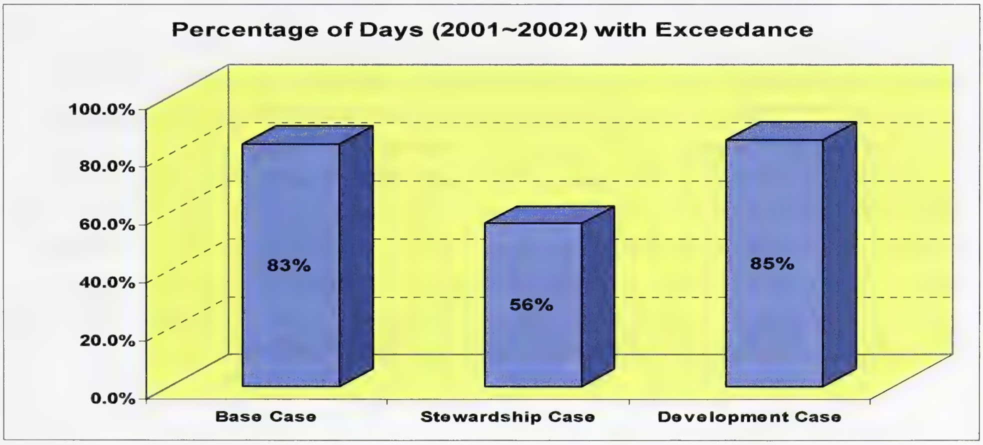
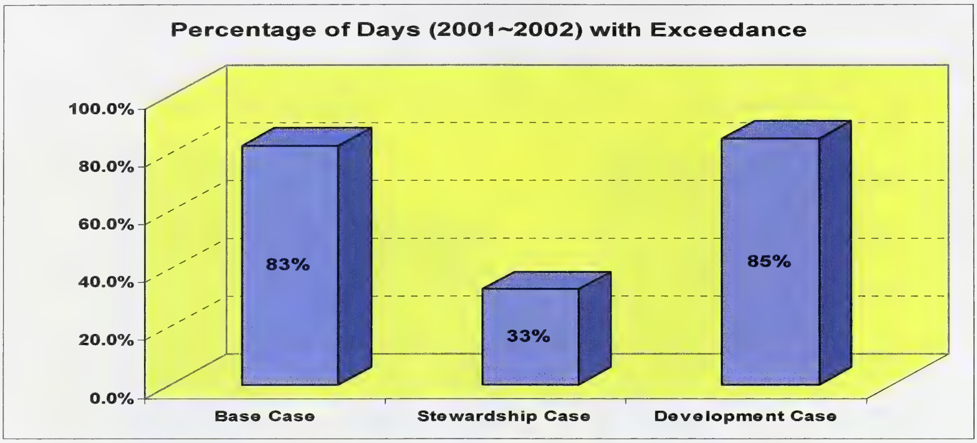


Figure WQ 14 (continued)

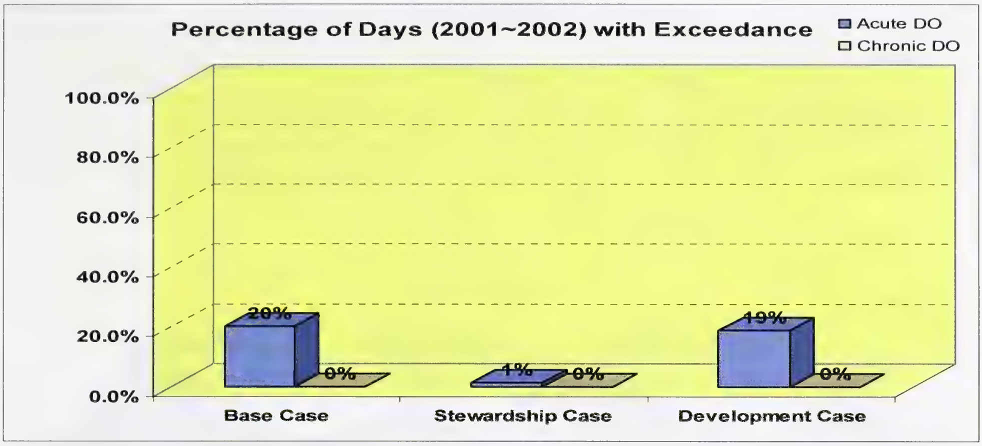
(c) Bassano Site



Exceedance of the dissolved oxygen chronic objectives is not expected to occur under the drought condition for all the scenarios (Figure WQ 15). However, in terms of the DO acute objectives, the exceedance frequencies elevate at the Stiers Ranch node under the drought condition for all the three scenarios, if compared with the results based on the long-term scenario simulations. The increase of exceedance frequencies of DO acute objectives at the Stiers Ranch node should be related to the expected higher nutrient concentrations, in particular phosphorus levels under the drought condition within the City of Calgary limit. However, exceedance of DO acute objectives would likely become much less or disappear for the reach downstream of the City of Calgary, based on the DO results from the lower reach assessment nodes of the Bow River. As discussed above, the nutrient loadings going to the lower Bow River are predicted to become less significant under drought condition because of decreased storm-water sourced contributions. In addition, the river re-aeration process would also recover the DO naturally along the travel of the flow away from the City Limit.

Figure WQ 15
Dissolved Oxygen Exceedance for SSRP Drought Scenarios

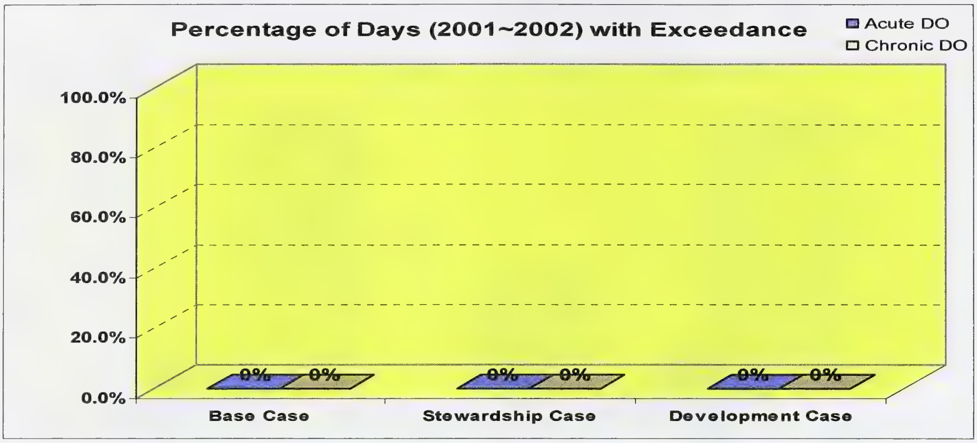
(a) Stiers Ranch Site



(b) Carseland Site

Figure WQ 15 (continued)

(c) Bassano Site



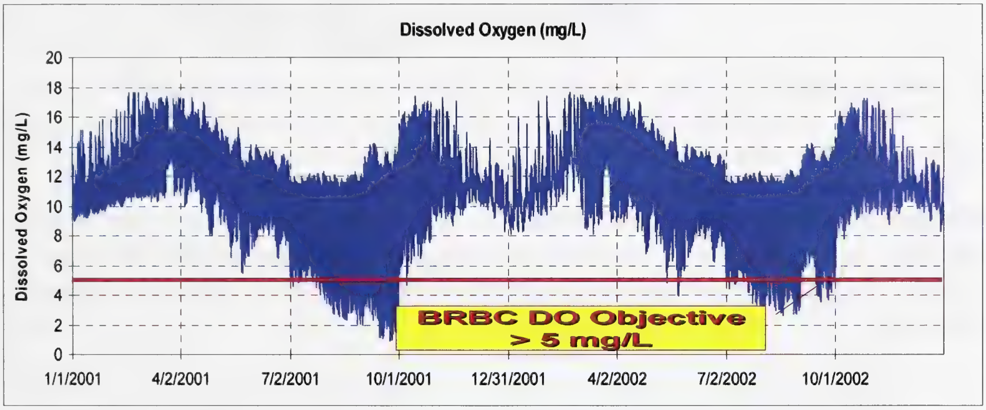
Since DO is considered as the most critical water quality parameter in this study, a more detailed analysis of DO exceedance was presented in Figure WQ 16 which compares the predicted dissolved oxygen time-series and the exceedance frequencies of the acute DO WQO at the Stiers Ranch site under the back-to-back drought condition for the three SSRP scenarios. The results suggest that the acute DO exceedance frequencies during both drought years are all expected to be higher than the DO exceedance frequencies based on long-term simulations. The acute DO exceedance frequencies are 21% in 2001 and 20% in 2002 individually under the drought condition of the Base Scenario, in comparison to only 6% based on the long-term results of the Base Scenario. It is also observed that the predicted low DO condition during the second drought year is improved if compared with the results of the first drought year. However, the improvement of DO conditions during the second drought year is insignificant, and likely related to the slightly reduced return flows from the City of Calgary and the decreased amount of sediment fluxes during the second year of the back-to-back drought event. More investigation is required to understand and validate this phenomenon.

Figure WQ 16
BRWQM Predicted Dissolved Oxygen Exceedance at Bow River Stiers Ranch Site under Drought Condition

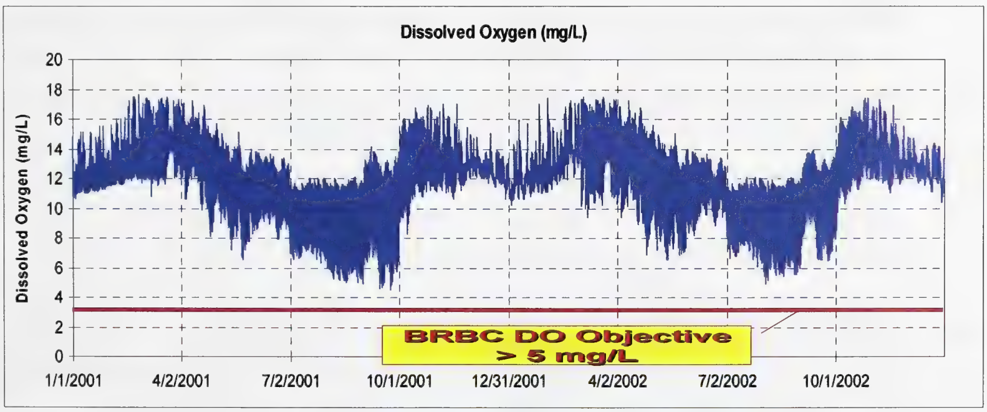
(a) Acute DO Exceedance Frequencies

	2001	2002
Base Case	21%	20%
Stewardship Case	2%	0.3%
Development Case	22%	16%

(b) Base Case



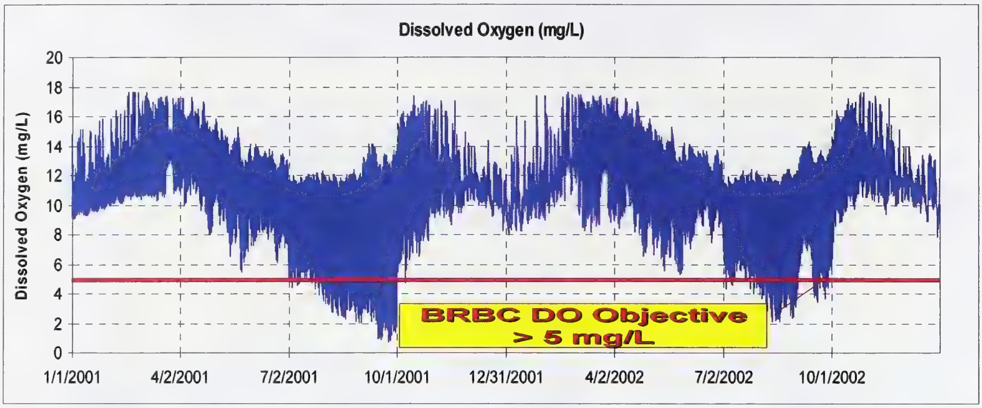
(c) Stewardship Case



(Figure continues on next page.)

Figure WQ 16 (continued)

(d) Development Case



BRWQM Drought Modelling Key Findings

The following key findings are derived based on the analysis and comparison of the drought simulation results against the long term simulation results for the three SSRP scenarios:

- Dissolved oxygen and nutrient conditions are expected to become worse under the drought condition for the Bow River reach within the City of Calgary limit, because of the decreased amount of upstream water to assimilate the major waste loadings from Calgary's WWTPs. However, the DO and nutrient conditions would become much more improved for the lower reach of the Bow River, due to decreased source loading from this range of river as well as the river's self-remedy functions such as re-aeration and bio-chemical oxidation;

- TSS conditions are expected to be improved under the drought condition due to the fact that most TSS loadings to the Bow River are associated with the storm-water inflows, which would become much less significant under dry condition;

- The overall water quality risks associated with drought conditions are still much less for the Stewardship Scenario if compared with the Base and Development Scenarios, due to lower amounts of water diversions at the upstream of the Bow River as well as the reduced wastewater returns from Calgary's WWTPs.

CLIMATE CHANGE AND VARIABILITY IMPACTS ON HYDROLOGY

Two contracts were awarded to study the impact of Climate Change and Variability on Hydrology, primarily on natural surface water supply. Under a Federal and Provincial Joint Initiative on Climate Change Adaptation Study, a contract was awarded through NRCAN (Natural Resources Canada) to Dr. Dave Sauchyn, University of Regina to study climate variability in SSRP. Another contract was awarded by AENV to Golder Associates to model the impacts on Climate Change and Variability on the hydrology of SSRP. The approach, scope and findings of these studies are summarized in the following.

Climate Variability Study of the SSRP Area

The major challenge from climate change in the SSR is not a shift in average climate. Rather, the challenge is that climate extremes, already a characteristic of Alberta's climate, will be amplified and there will be more extremes and departures from average conditions. From a water management perspective, it is necessary to know how water levels will fluctuate around the trending mean, and how that will affect the total water balance. An understand the severity and frequency of wet and dry years is also needed. For instance, we can have five "above average" and five "below average" years occur randomly in a decade which gives us an "average" overall. However, if we were to have those five "dry" years occur in a row (a severe drought), we would need to have considered how to manage the impacts.

Knowledge of the future distribution of water among years, decades and watersheds will assist decision makers to address adaptation options, adaptive management practices and appropriate policy for planned adaptation to climate change.

Alberta has from 50 to 100 years of measured and recorded *(instrumental)* data on most major rivers. This is considered to be a relatively short period of time with a limited amount of long-term variability having been measured. Longer records can show us more and increase our understanding of the history of water availability.

One way to get longer records is through secondary data (often referred to as *proxy data*). Areas of study like paleohydrology, for example, involve reconstructing past hydrology using geological information. The study of natural environments like tree ring information and lake sediment data are sources of secondary data.

Using tree ring data in the SSRB, the following information has been gathered. For the 387-year **Oldman River** record, the longest wet interval occurred from 1897 to 1913. This is the period when most Euro-Canadian settlers arrived in the region. The longest dry interval was from 1862 to 1876, shortly prior to settlement. For the **South Saskatchewan River mainstem**, the longest wet interval was from 1825 to 1841 and longest dry interval was during 1552 to 1571. The SSR record extending to 1400 is characterized by low flows from the 1470s to the 1570s, with extreme drought in the

1560s. The earliest severe hydrological drought in both basins occurred from 1717 to 1721, when at least one of these years was ranked as one of the ten driest years. Both reconstructions had only one drought year in the post-settlement (instrumental) period; 1985 in the Oldman River and 1919 in the SSR. Although the 1930s are considered one of the worst droughts in memory in western North America, that period does not rank as an extreme drought in either the Oldman or the SSR reconstruction. This suggests that as bad as it may have been, much more extreme droughts are possible.

Sea surface temperatures in the Pacific and Atlantic Ocean basins are a primary driver of climate variability. Indexes have been developed to measure sea surface temperature patterns (which includes El Niño Southern Oscillation, Pacific Decadal Oscillation (PDO), and North Atlantic Oscillation). When these index values are linked back to our hydrologic records, they demonstrate that changes in sea surface temperatures cause much of western Canada's variability in climate from year-to-year and over the decades. The PDO's regional importance is further underlined by stream flow reconstructions for the South Saskatchewan River Basin which show a PDO-like signal for the past six centuries, including prolonged 20-35 year low-flow periods.

Increased variation in climate could result in drought events, excess moisture or peak flood events. Modeling may help us to anticipate the frequency, length and severity of such events. Because the way the future climate will unfold can't be exactly predicted, there will be work done to describe the likely *probabilities* of departing from the expected average conditions. By using all of the information from the models and the measured and secondary data records, there will be an effort to describe the chances of seeing certain extreme conditions.

Hydro-Climate Modeling of the SSRP Area

Golder Associates Ltd. was contracted to undertake a modelling exercise using the HSPF hydrologic model to simulate the hydrologic effects of forecasted future climate change scenarios on water supply in the SSRP area. HSPF stands for (Hydrologic Simulation Program Fortran). The HSPF model uses information such as the time history of precipitation, temperature, relative humidity, wind speed and solar radiation; land surface characteristics such as land use patterns; land management practices and soil data to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed. The HSPF model can be used as an effective tool to predict flow rates, sediment loads, and nutrient/pesticide concentrations at sub-watershed level. It contains a water quality component which can be developed as a water quality model.

In order to simulate the impact of climate change on the stream flow in SSRP Area, the HSPF hydrologic model was set up for the five major basins in the SSRP, namely, Milk River Basin, Bow River Basin, Oldman River Basin, Red Deer River Basin and South Saskatchewan River Basin. The calibrated model was used to simulate statistically down-scaled temperature and precipitation changes predicted by five Global Circulation

Models (GCM) and associated scenarios and for two time periods: 2011-2040 (2020s) and 2041-2070 (2050s). Each GCM scenario reflects a possible temperature-precipitation condition that spans the range of expected conditions as follows:

- CCSRNIES-A1F1 — Warmer and drier than median conditions.
- CGCM2-B23 — Cooler and drier than median conditions.
- HADCM3-B2B — Median conditions.
- HADCM3-A2A — Warmer and wetter than median conditions.
- NCARPCM-A1B — Cooler and wetter than median conditions.

The model simulations with the GCM-scenarios reflect changes in 30-year mean temperature and precipitation. The hydrologic simulations do not reflect changes in future climate variability. Changes in future climate variability were estimated from simulated flow series generated from a recent study by Sauchyn *et al.* (2010) to assess changes in annual flows in the Oldman and Waterton rivers due to predicted changes in climate. The coefficient of variation (CV) of an annual mean flow series, which is the ratio of the standard deviation and the mean of the series, can be used as an indicator of flow variability. Changes in variability in annual mean flows were incorporated in the flow series simulated using HSPF and the five GCM-scenario predictions.

The HSPF hydrologic model was calibrated to reproduce most observed annual and monthly flows to within the required statistical criteria. Discrepancies were still larger than the target values because of uncertainties in the transfer of recorded precipitation data to sub-basins without local precipitation stations and for low winter flows in some systems. Changes to the nearest 5% (comparing simulated baseline and future annual flows) in mean annual flows in the Milk River, Bow River and Oldman River basins using the climate predictions from the five GCM-scenario 2020s range as follows:

- CCSRNIES-A1F1 — Warm-Dry — -15% to -30%
- CGCM2-B23 — Cool-Dry — -10% to -30%
- HADCM3-B2B — Median conditions — -5% to -15%
- HADCM3-A2A — Warm-Wet — -5% to 5%
- NCARPCM-A1B — Cool-Wet — -5% to +10%

Summary of findings

- The larger decreases in mean annual flows tend to occur for basins such as the Milk River Basin with low water yield in most parts of the basin.

- The larger increases tend to occur in sub-basins at higher elevations, such as Bow River at Banff.

- The effects (increases or decreases in flows) also tend to vary by month, with increases in mean monthly flows occurring during April and May, and decreases in mean monthly flows occurring during August, September and October.

Changes to the nearest 5% (comparing simulated annual flows between 1952 and 1999 with flows between 2004 and 2051) in mean annual flows in the Oldman River near Lethbridge and Waterton River at Waterton Park as predicted by eight (8) GCMs that incorporate climate variability from proxy data (Sauchyn *et al.* 2010) range as follows for two (2) selected scenarios:

- Oldman River – 8 GCMs for Scenario A1B 0% to -30% with an average of -10%

- Waterton River – 8 GCMs for Scenario A1B 0% to -15% with an average of -10%

- Oldman River – 8 GCMs for Scenario A2 -5% to -30% with an average of -15%

- Waterton River – 8 GCMs for Scenario A2 -0% to -15% with an average of -10%

The results from the HSPF simulations and from the simulations incorporating climate variability, two independent approaches with different input data and assumptions, seem to be in agreement for the range (generally between +5% and -30%) of potential effects on mean annual flows.

Percent changes (to the nearest 5%) in the variability of annual flows (as measured by the coefficient of variation CV of simulated annual flows between 1952 and 1999 with the CV of flows between 2004 and 2051) in the Oldman River near Lethbridge and Waterton River at Waterton Park as predicted by eight (8) GCMs that incorporate climate variability range as follows for two (2) selected scenarios:

- Oldman River – 8 GCMs for Scenario A1B +15% to +70% with an average of +30%

- Waterton River – 8 GCMs for Scenario A1B -20% to +80% with an average of +25%

- Oldman River – 8 GCMs for Scenario A2 -30% to +125% with an average of +25%

- Waterton River – 8 GCMs for Scenario A2 -30% to +130% with an average of +20%

Based on the above results, an average change in CV of about 25% was assumed to occur in the future (2011-2040) HSPF simulated series to account for changes in climate

variability. The effects of the change in climate variability (change in CV of about 25%) on indicators of the low and high flows (10-year dry and wet annual flows, and 100-year dry and wet annual flows) in the Milk River, Bow River and Oldman River basins were estimated in terms of future HSPF simulated series with changes in variability incorporated compared to the unmodified future HSPF simulated series. The effects are predicted to be as follows:

- Further decreases in low flows of the order of -10% to -25% for the 10-year dry low flow
- Further decreases in low flows of the order of -25% to -95% for the 100-year dry low flow
- The larger decreases occur in basins such as the Milk River Basin, while the decreases tend to smaller for the upper portions of the Bow River and Oldman River basins.
- Changes in the 10-year wet annual flows range from -5% to +10%, depending on basin and GCM-scenario.
- Changes in the 100-year wet annual flows range from -5% to +15%, depending on basin and GCM-scenario.

Overall findings

- The impact of climate change on SSRP annual stream flow ranges from +5% to -30%.
- Climate variability would further decrease the stream flow by 25% or more in dry years, and to a much lesser extent in wet years.

This suggests that low annual flows are affected to a larger degree by changes in climate variability than are high annual flows, which has implications for water management in the moisture-limited environment of the low basin yield areas of the SSRP.

OTHER ACTIVITIES AND FUTURE STEPS

A number of modelling initiatives are planned or underway:

CA Model

(Cellular Automata)

In 2008, the University of Calgary in partnership with Alberta Environment (AENV) and the Calgary Regional Partnership developed a CA model to simulate land-use changes in the Elbow River watershed. Their results demonstrated that the model represents the dynamics in the study area when compared to the historical land-use maps for the region. Additional simulations using constraints demonstrated the usefulness of this model for regional planners who wish to examine the possible outcomes of a development policy.

Cellular Automata models can be constrained by other "A-spatial models", like a population growth model, water allocation or hydrologic model. They can be constrained by specific rules that limit the quantity of land that should change from one land use to another, or that encourage or forbid land-use changes in a specific area in order to reflect local tendencies. Moreover, CA models are frequently used as spatial decision support tools for planners, because they can be designed to test "what-if" scenarios and policies. They can potentially be used to model climate change effects on landscape/land use. A "proof of concept" project undertaken in 2009 determined that it was possible to create an interface between the WRMM Allocation model and CA.

Further CA development

It is planned to expand the existing CA model for the remainder of the Calgary Regional Partnership area and to develop an interface between the SWAT water quality model and CA.

Hydro-Climate Modelling

Certain deliverables from the HSPF model can be used in future work as outlined below:

- Natural flow time series will be used in the water supply allocation model (WRMM) to assess the inherent risk to surface water licences under the Water Act.
- A developed HSPF model has the potential for use in future water quality modeling.

On-going work on HSPF modeling under the South Saskatchewan Regional Plan (SSRP) can aid the department in development of long range planning and implementation tools to manage natural resources (e.g., land and water) and protect ecosystems. This would be accomplished by integrating climate change mitigation and adaptation opportunities surrounding climate change in regional planning processes.

Water Allocation Model

Long term projects currently underway for WRMM include:

- Completion of a Graphical User interface to make the model visual and easier to learn, and use.
- Increasing capacity so that much larger, more detailed models can be created.
- Adding the capability to do real time operational planning.
- Improving speed so that more complex models able to solve multiple time steps in one pass can be created.

Future initiatives:

- Using the results of Hydro-Climate Modelling work described above to examine impacts of changes to the water supply predicted within climate change scenarios.
- Exploring the feasibility of incorporating economic modules into the Water Allocation model or methods to interface models.
- Running the model on the web.

Water Quality Models

Future initiatives:

- Complete BRWQM from Bassano to the Mouth.
- Conduct Phase 3 of the Bow Pilot study.
- Explore model interfaces between HSPF and MODFLOW (regional scale); and SWAT and MODFLOW (local scale).

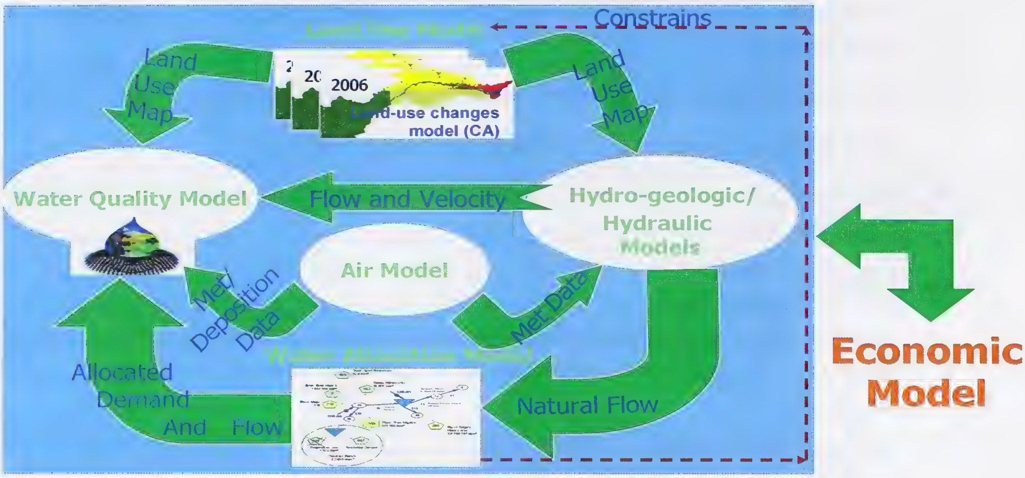
Natural Flow

Update the natural flow data used in the water allocation model and other analysis beyond 2001 (the last year of comprehensive information).

Integrated Modelling System

All of these existing and proposed modelling activities described above can contribute to the development of an integrated modelling system for the SSRP as shown in the following Figure O1.

Figure O1
Integrated Modelling System



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Appendix A
Water Allocation Model

WRMM CONFIGURATION

The following sections describe the general configuration of the Water Resources Management Model for the South Saskatchewan Basin.

Water Supply

Water supply to the SSRP is primarily from snowmelt in the Rocky Mountain headwaters of the Red Deer, Bow, Oldman and Milk basins. Precipitation events throughout the basin contribute additional water. The SSRP water supply is characterized in its natural state in the WRMM as though no human activity had occurred. This is referred to as natural flows.

Historical natural weekly averaged flows for the period 1928-2001 are obtained from records of stream flow gauges, reservoir storage/releases and consumptive diversions/ return flows. Natural flows are computed at a number of points within the sub basins by adding back any water stored or diverted (and subtracting any water returned) to the recorded stream flow at points above the recording locations.

An exception to the use of natural flow supplies is the St. Mary River which is apportioned between Canada and the United States under Article VI of the 1909 Boundary Waters Treaty. For the 1928-2001 period, the weekly Canadian entitlement is used in the modelling of the Southern Tributaries.

Alberta/Saskatchewan Apportionment

The governments of Alberta, Saskatchewan, Manitoba and Canada entered into a Master Agreement on Apportionment for sharing the waters of eastward flowing interprovincial streams. Schedule A of the 1969 agreement outlines how water is apportioned between Alberta and Saskatchewan. The following table summarizes Alberta's commitment.

Annual natural flow volume	Flow that Alberta must pass to Saskatchewan
Greater then 5.2 million dam³ (4.2 million acre-ft)	Half the natural flow
2.6 million dam³ to 5.2 million dam³	Alberta may keep more than half the natural flow provided flow passing to Saskatchewan does not drop below 42.5 cms (1500 cfs.)
At any time	Subject to the above conditions, passing flow to Saskatchewan cannot go below 42.5 cms or half of the instantaneous natural flow (whichever is less).

1 dam³ (1 cubic decametre) = 10x10x10 cubic metres = 1000 cubic metres = 1 megalitre

These conditions are included in the SSRB main model. Meeting apportionment is a high priority in the model.

Licensed Consumptive Demands

The largest demands in the South Saskatchewan Regional Planning area are from irrigation districts and private irrigation which vary with climatic conditions for the year. These variable demands and return flows are computed by the Irrigation District Model (IDM) of Alberta Agriculture and Rural Development (AARD). Different demand sets for irrigation demands prepared for the Base Case, Stewardship and Development scenarios were applied in the WRMM model.

Compared to irrigation demand, non-irrigation demands are generally small. Furthermore, in the case of municipalities a large proportion of the diversion is returned to the streams. Non-irrigation is modelled as non-varying from year to year.

The oldest licences issued in Alberta including the major irrigation districts which are among the most senior licences, often have no instream conditions attached. More recent licences issued since the 1980's will have Instream Objectives attached as conditions of withdrawal. The newest licences issued after 2005 will have Water Conservation Objectives as established in the South Saskatchewan River Basin Plan (2005). More information on Instream Objectives and Water Conservation Objectives is provided below.

Instream Flow Needs, Instream Objectives and Water Conservation Objectives

Over the course of the South Saskatchewan River Basin planning exercise (2000 to 2005), new terms were added to the vernacular that are commonly referenced today. These are Instream Flow Needs (IFN) and Water Conservation Objectives (WCO) which are added to the definitions of Instream Objectives (IO) and Fish Rule Curves (FRC) that were in place prior to 2000.

<u>Existing Instream Objectives</u>

Existing Instream Objectives are flows that are included in conditions attached to licences issued prior to the SSRB approved water management plan. An instream objective describes the desired level of flow or water quality that considers both instream and withdrawal (e.g., municipal, irrigation, industry) needs. Licensees are not permitted to withdraw water when river flows fall below the specified IO. Alberta Environment generally operates provincial infrastructure to meet the current IO.

Red Deer River basin

On the mainstem reaches from Dickson Dam to the Saskatchewan border, the following IOs have been applied:

- 8.50 m^3/s (300 ft^3/sec) for irrigation licences;

- $4.25\ m^3/s$ ($150\ ft^3/sec$) for non-irrigation licences.

The effect of these IOs on protection of the aquatic environment is not known.

Bow River basin

There are five main stem reaches from Ghost Reservoir to Bassano Dam. These are:

- Ghost Reservoir outlet to Bearspaw Reservoir outlet;
- Bearspaw Reservoir outlet to Elbow river confluence;
- Elbow river confluence to Highwood River confluence;
- Highwood River confluence to Carseland weir;
- Carseland weir to Bassano dam.

Each reach has an IO, which is based on a relationship known as the 80% habitat fish rule curve (80FRC). The IO in these reaches is based on habitat only and does not include water quality (temperature and dissolved oxygen) protection parameters.

The reach below Bassano to the mouth has three IO values:

1. $39.6\ m^3/s$ ($1,400\ ft^3/sec$) for all licences except the Eastern Irrigation District (EID);
2. $2.83\ m^3/s$ ($100\ ft^3/sec$) for EID's 1963 licence (1903 priority);
3. $11.3\ m^3/s$ ($400\ ft^3/sec$) for EID's 1998 licence.

The effect of these IOs on protection of the aquatic environment is not known.

The Highwood River has:

- no IO for private withdrawals;
- 1994 Operating Guidelines IO applied to the Women's Coulee and existing Little Bow diversions of $1.70\ m^3/s$ and $2.83\ m^3/s$ (60 and 100 ft^3/sec), respectively;
- The Highwood Diversion Plan established an IO which is applied to the operation of the expanded $5.66\ m^3/s$ ($200\ ft^3/sec$) Little Bow canal. This IO is a compromise between the technically established IO for protection of fish, water quality and flushing flows, and irrigation operations in the basin.

Oldman River basin

There are six main stem reaches from the Oldman Reservoir to the mouth. They are:

- Oldman Reservoir outlet to Pincher Creek confluence;
- Pincher Creek confluence to the Lethbridge Northern Irrigation District (LNID) weir;
- LNID weir to Willow Creek confluence;
- Willow Creek confluence to Belly River confluence;
- Belly River confluence to St Mary River confluence;
- St Mary River confluence to Mouth.

Each reach has an IO that is the greater of the 80% habitat fish rule curve (80FRC) and water quality (temperature and oxygen) protection IO flows.

The three Southern Tributaries to the Oldman River each have minimum flows specified in the SSRB Regulation. They are:

- 2.27 m^3/s (80 ft^3/sec) for the Waterton River at the mouth;
- 0.93 m^3/s (33 ft^3/sec) for the Belly River below the Belly River Diversion,
- 2.75 m^3/s (97 ft^3/sec) for the St. Mary River at the mouth.

The effect of these IOs on protection of the aquatic environment is not known.

South Saskatchewan River sub-basin

From the confluence of the Bow and Oldman rivers to the Saskatchewan border, an IO of 42.5 m^3/s (1,500 ft^3/sec) is attached to licences.

The effect of this IO on protection of the aquatic environment is not known.

<u>Instream Flow Needs</u>

Instream Flow Needs were developed by a Technical Instream Needs Group and documented in a report that was prepared as part of the SSRB planning exercise: "*<u>Instream Flow Needs Determinations for the South Saskatchewan River Basin, Alberta, Canada</u>*"

That report details the quantitative estimates of the flows required to protect the aquatic environment for several stream reaches with the SSRP area. Four components are used as surrogates for the overall aquatic environment: Water Quality (Temperature, Dissolved Oxygen and Ammonia), Fish Habitat, Riparian Vegetation and Channel Maintenance. For each of the reaches, 52 weekly flows that vary from year to year are recommended to protect the aquatic ecosystem. Flow

requirements to fully protect the aquatic environment are described in the report by the acronym "IFN" to be distinguished from existing instream objectives "IO".

Water Conservation Objectives

Water Conservation Objectives (WCO) are defined in the *Water Act* and established in Water Management Plans. There is not enough flow in the rivers of the SSRB to satisfy the IFN flow requirements for the long-term and satisfy existing licence allocations, let alone allowing for future licences to permit growth in consumption. A compromise between existing Instream Objectives and IFN was decided upon when developing Water Conservation Objectives in the SSRB water management plan.

Water Conservation Objectives established in the SSRB water management plan for the Bow, Oldman and South Saskatchewan River Sub-basins in 2005 are included in the model. Any licences issued for applications received after May 1, 2005 are subject to the following water conservation objective: 45% of the natural rate of flow, or the existing instream objective plus 10%, whichever is greater at any point in time.

The WCO for the Red Deer River is similar, but slightly more detailed. Upstream of the confluence with the Blindman River, to Dickson Dam new licences or existing licences with a retrofit provision (i.e., the *Water Act* Director may amend the minimum passing flow condition of the licence) have a WCO equal to the rate of flow that is 45% of the natural flow, or 16 cms, whichever is greater at any point in time.

Downstream of the confluence with the Blindman River to the Saskatchewan border, new and future licences that withdraw water from November to March inclusive have a WCO equal to the rate of flow that is 45% of the natural flow, or 16 cms, whichever is greater at any point in time. New and future licences that withdraw water from April to October inclusive have a WCO equal to the flow that is 45% of the natural flow, or 10 cms, whichever is greater at any point in time. Existing licences with a retrofit provision have a WCO equal to the flow that is 45% of the natural flow, or 10 cms, whichever is greater at any point in time.

Modelling of Licences and Priorities

The model allocates available water supply to the various demands in order of licence priority and makes best use of storage structures to mitigate shortages in times of low water supply and high demands.

All major licences are represented according to their priorities and with their restrictions, e.g. stage/flow, Instream Objectives and WCO, where applicable. Large licences of the major irrigation districts are modelled individually; however, it is not possible or practical to model all other licences in the SSRP individually because there

are so many. Such licences are grouped together by river reach into categories of senior and junior. Categorization as senior or junior is based on conditions attached to a licence, priority date of the licence relative to introduction of the Instream Objective conditions, and construction of Alberta Government on-stream storage.

In the Red Deer River, licences earlier than 1977 (when Gleniffer Reservoir was licensed) are senior, since they must be satisfied before Gleniffer Reservoir can store water. Licences after 1977 are junior, since they receive supply after Gleniffer, which can fill as often as needed in order to maintain a recreation level and also to release water for IOs and apportionment.

An identical situation occurs in the Oldman main stem where junior licences are those after 1988 when the Oldman Reservoir was licensed.

In the Bow sub-basin, junior licences are defined as those licences that are subject to the 80%FRC (described above), which has been applied since the late 1980's and licences where an instream objective can be stipulated by a *Water Act* Director.

Water Storage and Operations Management

Major storage structures are included in the models. They are multi-purpose facilities intended for water management, flood control, erosion control, flow regulation, hydropower, conservation and recreation and have differing operating objectives. The structures have specific operating curves that are used in the WRMM models.

Red Deer River (Dickson Dam and Glennifer Lake)

The operating objective of the Dickson Dam is to provide an assured downstream water supply, primarily during the winter months, by providing a minimum release rate of 16 cubic meters per second (cms).

Gleniffer summer recreation levels are always protected in the model. Any remaining water can, at the discretion of the Alberta Government, be released to supply junior licences, which cannot be completely satisfied from natural flow. However, reservoir operating rules must be followed in order to ensure there is enough water in the reservoir to meet priorities of recreation, IO and apportionment. Therefore, there are times when the additional water needed to supplement junior licences is not available for release.

Bow River Hydroelectric Facilities

The major water power projects in the Bow River basin are owned and operated by TransAlta Corporation. Their operations are part of the TAU WRMM model.

Eleven generation sites are located within the basin. The dams associated with each site are operated primarily for the purpose of hydro-electric power generation. The

dam sites and storage reservoirs also provide benefits for recreation, flow regulation and, in some cases, limited flood reduction.

Storage volumes and reservoir levels rise and fall throughout the year depending on generation requirements. Typically, the reservoirs are filled during the spring and summer runoff period and are depleted during the winter months. Some generation sites have little or no storage capability and are considered "run of the river" developments where water is passed through the generation plant, as soon as it arrives from upstream sources.

Southern Tributaries Waterton-St. Mary Headworks System (including the Waterton River and St. Mary River Dams)

The primary use of the system is to deliver water to the irrigation districts south of the Oldman River.

Oldman River Dam

The Oldman Dam has several objectives including the following:

- Supply existing and future consumptive water demands of municipalities, industries and agriculture;
- Provide flexibility in meeting Alberta's interprovincial commitments under the Master Agreement on Apportionment;
- Provide flows in the Oldman River downstream from the dam that will maintain water quality to ensure fish survival, enhance downstream recreational opportunities, and sustain riparian vegetation. Hydro-electric power generation also occurs. The hydro-electric plant is operated by a private developer in concert with the operational requirements of Alberta Environment.

Sufficient storage is protected in the Oldman Reservoir in the model so that 42.5 m^3/s (1500 ft^3/sec) is always maintained in the South Saskatchewan River (the IO condition on senior licences). Similar to the Dickson Dam, there are times when additional water needed to supplement junior licences is not available for release, which can lead to severe deficits to this group on the Oldman River.